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**Protected area management under climate change**

**A framework for decision making**

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## **Abstract**

There are over 200,000 protected areas today conserving about 15.4% of the world's terrestrial and inland waters, and around 3.4% of the oceans (Juffe-Bignoli et al. 2014). They provide an effective means of supporting conservation of ecological, cultural and social values. However, they experience a range of threats that park managers must deal with, and now face a new suite of impacts from anthropogenic climate change. Current protected area management approaches may not be adequate to conserve park values as they become more threatened as climate alters because parks were originally developed and managed with the notion of static boundaries with the aim of maintaining current values. Many existing strategies and approaches do not necessarily answer the questions managers need for practical application day to day management as available tools are either lacking in data or very specialised, making them impractical for natural resource managers with limited expertise. There is a need for a methodology and guidelines to assist protected area managers in understanding how their parks and reserves will respond to future climate change so they can make informed decisions and devise possible management strategies.

The aim of this research was to investigate approaches to managing climate change impacts on protected areas through understanding and addressing management and planning at the park level. Three key points are addressed to accomplish this, understanding socio-ecological attributes for effective park planning and management, understanding park climate change impacts, and incorporating these into decision making and adaptive management of protected areas. This was applied to four of Queensland's Gondwana Rainforests of Australia World Heritage listed protected areas, Springbrook, Lamington, Mount Barney and Main Range National Parks.

Most research and planning for climate change is undertaken at a higher strategic level (i.e. regional level and above) with a lack of implementation on-park. Other research and planning effort has been focused on 'off-reserve' strategies to complement and support protected areas on a regional scale. Implementation of socio-ecological values and perceptions in park management are only beginning to occur, which is now recognised as an important factor in adaptive management for protected areas to increase effective management. A climate change adaptation management framework was developed (Chapter 2) to strengthen the relationships between climate change science and the socio-ecological drivers, and on-park management. It sets out the context of the situation to clarify the protected area system's attributes and how they inter-relate. It presents a decision making framework based on a set of strategies aimed at adapting on-park management to climate change. The strategies are aimed at both accepting climate change and the transformations it

brings to ecosystems or preventing climate change impacts on park values with an aim to maintaining current systems under new climate variations.

Most protected areas require the cooperation and support of local communities and an understanding of stakeholder values and perspectives. Collaborative approaches to management are most likely when there are shared perspectives on key issues. Chapter 3 presented results of a survey of the local community, protected area neighbours and Queensland Parks and Wildlife Service to gain an understanding of the public's and natural resource managers' perceptions of climate change, likely impacts on the local natural environment and management of protected areas. The community, protected area neighbours and park managers in the Scenic Rim had a good understanding of climate change and its likely impacts and were concerned about the natural environment. Managers' perceptions were largely aligned with the perceptions of the local community but with significant differences in views concerning management of recreation, feral species and fire. Where perceptions align, programs and conservation practices can be undertaken in a cooperative way that should minimise obstacles to successful implementation. Differences can pose challenges to park management.

Protected areas will vary in how they respond to climate related threats and impacts. An important step in adapting protected area management to respond to climate change is identifying how protected areas and their values may be impacted. A set of Bayesian belief networks were developed (Chapter 4) to assess impacts and management issues for three key values (stream-dwelling frogs, cool temperate forest and recreational walking access) across the four Gondwana parks. The aim was to assess how those values may be impacted by climate change, how the parks differ in relation to likely impact and options for management adaptation. Depending on a protected area's physical and socio-ecological characteristics, the values were affected by climate change differently across the parks and park management responses will need to take account of these differences.

Chapter 5 contains an analysis of the management options (Chapter 2) through a workshop with Queensland Parks and Wildlife planners and managers to assess probable management strategies for the four Gondwana parks for the three key values assessed in Chapter 4. The strategies were assessed for feasibility (cost and probability of success) and the social, ecological, economic, cultural and agency/political implications. Decision making is a complex process and strategies that result in high feasibility (i.e. low cost/high success) are not always the most appropriate. There are many constraints and consequences that can substantially influence management decisions. Most

parks will benefit from implementing a range of strategies and will be required to become adaptive in their management. Park managers will have to become more inventive and flexible in their approach to management, more efficient in allocating and utilising resources and make decisions that may go against the community's and their own principles and values to maintain productive and sustainable protected areas under climate change.

### **Declaration by author**

This thesis *is composed of my original work, and contains* no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

I have clearly stated the contribution of others to my thesis as a whole, including statistical assistance, survey design, data analysis, significant technical procedures, professional editorial advice, and any other original research work used or reported in my thesis. The content of my thesis is the result of work I have carried out since the commencement of my research higher degree candidature and does not include a substantial part of work that has been submitted *to qualify for the award of any* other degree or diploma in any university or other tertiary institution. I have clearly stated which parts of my thesis, if any, have been submitted to qualify for another award.

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### **Publications during candidature**

Tanner-McAllister, SL, Rhodes, JR & Hockings, M 2014, 'Community and park manager's perceptions of protected area management: a southeast Queensland study', *Australasian Journal of Environmental Management*, vol. 21, no. 3, pp. 1-17.

### **Publications included in this thesis**

This thesis contains one jointly authored published paper and one jointly authored paper that has been submitted for publication. Contributions by co-authors are indicated below.

1. Tanner-McAllister, SL, Rhodes, JR & Hockings, M 2014, 'Community and park manager's perceptions of protected area management: a southeast Queensland study', *Australasian Journal of Environmental Management*, vol. 21, no. 3, pp. 1-17. – incorporated as Chapter 3.

| Contributor                            | Statement of contribution  |
|--|--|
| Sherri L Tanner-McAllister (Candidate) | Designed experiments (70%)<br>Wrote the paper (80%)<br>Statistical analysis of data (100%) |
| Professor Marc Hockings                | Designed experiments (30%)<br>Edited paper (10%)   |
| Associate professor Jonathan Rhodes    | Edited paper (10%)   |

2. Tanner-McAllister, SL, Rhodes, JR & Hockings, M 2016, 'A comparison of climate change impacts on park values in four Queensland World Heritage National parks in Australia', submitted to the *Australasian Journal of Environmental Management* – incorporated as Chapter 4.

| Contributor                            | Statement of contribution  |
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| Professor Marc Hockings                | Designed experiments (30%)<br>Edited paper (10%)   |
| Associate professor Jonathan Rhodes    | Edited paper (10%)   |

## **Contributions by others to the thesis**

### **Chapter 1**

This chapter was solely written by the candidate with editorial assistance from Marc Hockings and Jonathan Rhodes

### **Chapter 2**

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### **Chapter 3**

Tanner-McAllister, SL, Rhodes, JR & Hockings, M 2014, 'Community and park manager's perceptions of protected area management: a southeast Queensland study', *Australasian Journal of Environmental Management*, vol. 21, no. 3, pp. 1-17.

This chapter is an extension of a publication by the candidate, Jonathan Rhodes and Marc Hockings in *Australasian Journal of Environmental Management*. The idea for the chapter was conceived by the candidate and Marc Hockings and 100% of the analyses was conducted by the candidate. The chapter was solely written by the candidate with editorial assistance from Jonathan Rhodes and Marc Hockings.

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### **Chapter 5**

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## **Chapter 6**

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**Statement of parts of the thesis submitted to qualify for the award of another degree**

None

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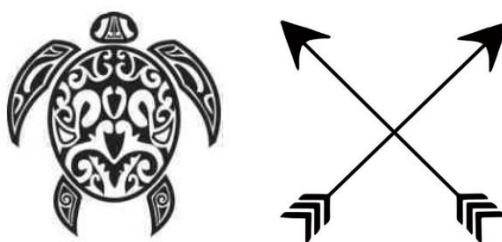
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protected area, climate change, adaptive management, bayesian belief network, socio-ecological, World Heritage, adaptation, conservation management, Queensland, impact

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For Georg and Karin.....

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## List of Abbreviations

CSIRO – Commonwealth Scientific and Industrial Research Organisation

QPWS – Queensland Parks and Wildlife Service

BBN – Bayesian Belief Network

UNESCO – United Nations Educational, Scientific and Cultural Organisation

SLOSS – single large or several small

IA – Integrated assessment

NSW – New South Wales

IPCC – Intergovernmental Panel on Climate Change

ARCS – Australian Rainforest Conservation Society

B&B – Bed and breakfast

Qld – Queensland

Cwlth – Commonwealth

CTF – Cool temperate forest

UNFCCC – The United Nations Framework Convention on Climate Change

RCP – Representative concentration pathways

DERM – Department of Environment and Resource Management

# Chapter 1

## Introduction

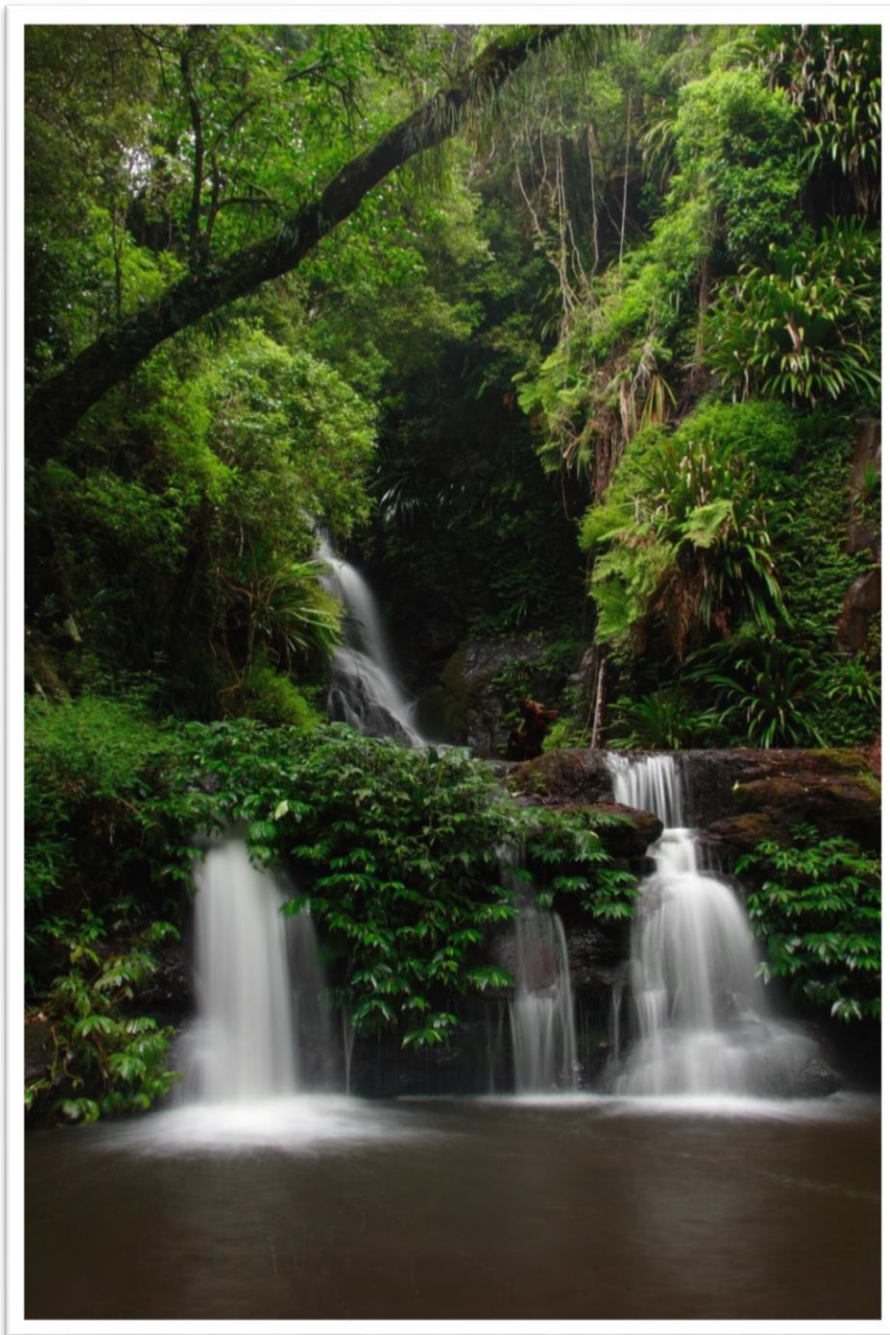


Plate 1 – Elebana Falls, Lamington National Park

**‘No river can return to its source, yet all rivers must have a beginning’ – Native American Proverb**



## **1.1 Conservation and protected areas**

A protected area is ‘a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values’ (Juffe-Bignoli et al. 2014). They are the cornerstones of nearly all national and international conservation strategies (Brooks et al. 2004) and provide the foundation for protecting biodiversity into the future (Timko & Satterfield 2008). Protected areas are well recognised as a key strategy in the prevention of biodiversity loss (Rodrigues et al. 2004; Hannah et al. 2007). They protect ecosystem health and biodiversity, provide ecosystem services and in many cases accommodate human communities (Hockings 2003).

Today, over 200 000 protected areas conserve about 15.4% of the world’s terrestrial and inland waters, and around 3.4% of the oceans (Juffe-Bignoli et al. 2014) and are one of the most significant uses of land and sea (Lockwood et al. 2006b). They provide an effective means of supporting conservation in a world of increasing land use conversion from native habitats (Ramankutty & Foley 1999; Kallimanis et al. 2015; Oakleaf et al. 2015). Protected areas are valuable due to their legal frameworks that offer long term stability for protection of land and water ecosystems and support from planning that provides direction and management (Lee & Jetz 2008).

Protected areas experience a range of threats with many complex and varied issues that park managers must currently deal with, and without appropriate management, park values could be lost (Worboys et al. 2006). Since their inception, protected areas have persisted in an environment within a fairly predictable range of climate variability (Landres et al. 1999; Baron et al. 2009). They now face increased climate change with a higher unpredictable range of variability predicted to result in increased ecosystem transformations, species movement and novel threats (Hole et al. 2009; Gonzalez 2010; Sehgal 2010).

## **1.2 Climate change**

Climate change is now a well-known and accepted phenomenon, it has occurred over the earth's history in varying degrees and is one of the most important factors in the earth's development (Pittock 2009). One of the challenges the human species faces today is how do we adapt and live with future climate change. Global warming is increasing at an extraordinary rate and human beings are endeavouring to find out what kind of changes can we expect in the future, and most importantly what are the impacts from those changes and can we do anything about them (IPCC 2014).

For the purposes of this thesis, climate change is defined as 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere which is in addition to natural climate variability observed over comparable time periods' (United Nations 1992). Human induced (anthropogenic) climate change incorporates changes in land and sea surface temperatures, changes in climate related events such as changes in rainfall, evapo-transpiration, sea-level rises and ocean acidification, changes to the thermo-haline currents, and changes to extreme weather events such as severe storms (IPCC 2014; Maxwell et al. 2015). It is important that we consider anthropogenic climate change because human influence is accelerating changes faster than in the past and many ecosystems are under stress from human impacts (Cooperative Research Centre for Tropical Rainforest Ecology and Management 2003; Perry 2015).

Predicting changes and impacts are important in preparation for responding to climate change. Predictions are used in developing context and understanding the extent of climate associated issues. Global climate models continue to improve in their reliability (Pittock 2009) with advances in modelling techniques, better understanding of climatic processes and increasing data collection. Regional predictions are more easily masked by climate variability and influenced by regional topography or processes (CSIRO & Australian Bureau of Meteorology 2007). Nonetheless there are still many uncertainties in projecting global and regional climate change.

### 1.3 Climate change and protected areas

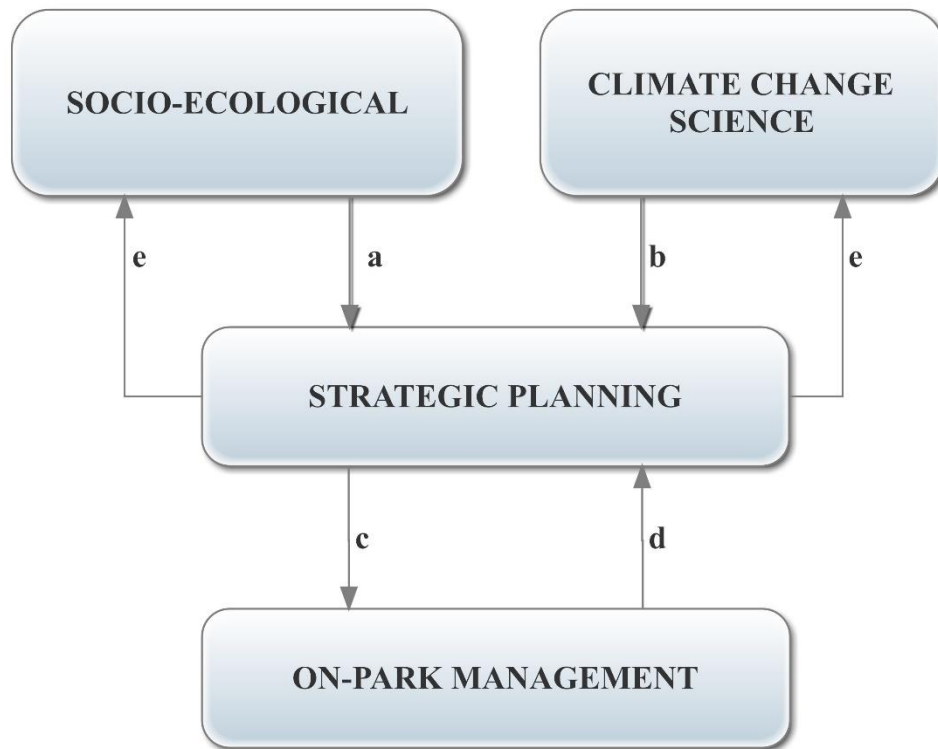
Traditionally, protected area management has been based on values and conditions of the past and managed today to maintain those values *in situ* (Hagerman et al. 2010b). The future climatic system protected areas will be facing is considerably different from recent climate and will impact on biodiversity, species distribution and abundances, species interactions, ecosystem processes, and exacerbate a variety threats to biodiversity (Hannah et al. 2002b; Hole et al. 2009; West et al. 2009). There are also concerns about how climate change will impact on tourism and recreational opportunities, and interruptions to ecosystem function and loss of ecosystem services (Dunlop & Brown 2008).

Current protected area management approaches may not conserve these areas adequately as climate alters. *In situ* park management has generally focused on building resilience of our natural resources with a strong focus on maintaining protected areas in their current state. With major transitions expected of our natural systems, natural resource managers may need to consider managing for change (West et al. 2009) and will have to determine how current management systems can cope with protected area values under future climate change. Strategies based on diversity and flexibility will be required to face the uncertainties and complexities of climate change in regards to protected areas (Baron et al. 2009). *In situ* protected area management will need to incorporate the broader landscape context taking into account the surrounding ecological and social factors. These will affect the resource condition of the protected area and pressures acting on their values and management.

More effective and innovative management strategies are needed to deal with the expected and unexpected impacts of climate change and to enhance resilience of our ecosystems (Steffen et al. 2009b). There is a research need for designing protection strategies incorporating climate change and data suitable to inform management action and a need for modifying and changing management strategies and priorities including determining the most suitable ways of incorporating climate change projections and impacts into protected area planning (Hilbert et al. 2007).

There are many management strategies and approaches available to assess and deal with climate change impacts (Hannah et al. 2002a; Peterson et al. 2003; Baron et al. 2009; Johnson & Weaver 2009; West et al. 2009). Most available tools are either lacking in data or very specialised, making them impractical for natural resource managers with limited expertise (Mawdsley 2011). They do not necessarily answer the questions managers need for practical application and only a limited number of tools bridge the gap between science and day to day management (Hannah et al. 2002a). There is still a need to investigate how conservation research and knowledge can be transformed into on-ground management (Lindenmayer et al. 2008).

Figure 1-1 illustrates the relationships between climate change science and socio-ecological factors with on-ground park management via strategic park planning. Strong links between these three elements will be important to adapt park management to climate change impacts. The relationship between ‘socio-ecological’ and ‘strategic planning’ (a) is the understanding of the socio-ecological environment of which park planning works within. This is important as protected areas are largely established and managed by beliefs, perceptions, attitudes and actions of society (Figuerola & Aronson 2006). The link between ‘climate change science’ and ‘strategic planning’ (b) is the means of incorporating climate change science into protected area planning. Scientific knowledge reduces uncertainty in park management which improves park effectiveness and efficiency (Addison et al. 2013). The knowledge and data integrated into ‘strategic planning’ about the socio-ecological environment and climate change science must then be incorporated into ‘on-park management’ (c). This link prepares protected area management for change and decreases the probability of maladaptive practices and policies (Stagl et al. 2015). A considerable amount of local park knowledge exists (i.e. park rangers) and the relationship between ‘on-park management’ and ‘strategic planning’ (d) provides the link to feed this information back into planning. Research and monitoring of climate change and social sciences for park planning and management should be guided by gaps in knowledge to improve park management effectiveness, the link between ‘strategic planning’ and ‘socio-ecological/climate change science’ (e).



**Figure 1-1 Conceptual model illustrating the relationships between science, socio-ecological factors and on-park management via strategic planning.**

At this time, the relationships between these elements are inadequate or non-existent resulting in lack of implementation of appropriate strategies at a park level (Sharp et al. 2014; Addison et al. 2015; Dutra et al. 2015). *In situ* park management dealing with climate change lacks the input of higher level planning and science, likewise on-park knowledge and management does not lead to relevant or practical solutions in strategic planning for climate change adaptation (Rannow et al. 2014; Addison et al. 2015; Geyer et al. 2015).

Considerable research has been undertaken to gain scientific understanding of climate change impacts and how it will affect protected areas (Gaston et al. 2008; Lemieux & Scott 2011; Groves et al. 2012; Perry 2015; Scriven et al. 2015). Incorporating science into on-ground park management however is inadequate and park managers still struggle in dealing with impacts on-park, particularly as impacts increase and novel threats emerge (Podesta & Halpin 2008). One of the key areas lacking in relation to protected area management are better planning tools that operate within a rapidly changing environment. Adaptive management is slowly being adopted, however the specific tools for on-park management are still lacking (Addison et al. 2015). Innovative strategies and tools will need to be flexible and adaptable with a long term

approach and have an understanding of socio-ecological values that will be affected by these changes if park managers are to succeed in effective management in response to climate change (Hilbert et al. 2007).

#### **1.4 Integration of climate change science and park management**

Most research and planning is undertaken at the strategic level with a lack of implementation (Pierce et al. 2005; Pressey & Bottrill 2009) and very few protected areas incorporate climate change into their planning and management at a park level (Poiani et al. 2011). Lack of implementation of adaptation strategies may be due to the perceived costs and shortage of resources, lack of localised climate change predictions and responses, uncertainty, absence of transformative strategies not yet fully developed, and competing priorities (Galatowitsch et al. 2009; Heller & Zavaleta 2009; Moser & Ekstrom 2010; Poiani et al. 2011; Jones et al. 2016; Wyborn et al. 2016). Other research and management effort has been focused on the matrix and surrounding land uses to complement and support protected areas or how protected areas contribute to biodiversity on a regional scale (Lawler 2009; Hagerman et al. 2010b).

There is a need for a methodology and guidelines to assist protected area managers in understanding how their parks and reserves will respond to future climate change so they can make informed decisions and devise possible management strategies. Poiani et al. (2011) have indicated that there is a substantial gap between theory and practice from their study of existing conservation strategies. They believe that climate change may require more emphasis to be given to transformative approaches including strategies aimed at managing for change and novel ecosystems. Protected area managers and scientists should increase their advancement of these approaches to outline and develop the next generation of conservation strategies in preparation of climate change impacts and changes (West et al. 2009; Poiani et al. 2011).

The other gap in research crucial to dealing with adapting conservation policy is how to incorporate on-park information and data into strategic planning (Hagerman et al. 2010b). There is increasing research into climate change adaptation options (Mawdsley 2011), however many of these are lacking in practicability. Lemieux and Scott (2011) surveyed a panel of protected area experts and approximately half of the adaptive management options identified by participants were assessed as definitely not or probably not implementable. There is a need for

park planners and managers to have tools to communicate better with park staff to deal with these sorts of issues.

There is a considerable amount of local knowledge that is not incorporated into strategic planning (Addison et al. 2015) even though it has been shown that park staff's local ecological knowledge is fairly accurate (Cook et al. 2014). There has been some progress to try and capture this information through tools such as the Rapid Assessment and Prioritization of Protected Area Management (RAPPAM) Methodology, the Management Effectiveness Tracking Tool (METT) and Enhancing our Heritage (EoH) that evaluate overall protected area effectiveness (Cook et al. 2010; Leverington et al. 2010; Stoll-Kleemann 2010).

Co-production of knowledge is an emerging concept of interactions between science, policy and practice, and collaborative learning between 'experts' (e.g. scientists) and 'users' (e.g. protected area managers) (Roux et al. 2006; Wyborn 2015b) and is showing positive social and ecological outcomes in dealing with environmental change and complex issues (Armitage et al. 2011; Berkes 2012). It is being used in climate change adaptation projects (Armitage et al. 2011; Hegger et al. 2012; Nagy et al. 2014; Shaffer 2014), protected area management (Ungar & Strand 2012; Cvitanovic et al. 2014a), and adaptive management and capacity (Robinson & Berkes 2011; Cvitanovic et al. 2015; Alessa et al. 2016). Use of co-production of knowledge is showing positive results in management of natural resources because it provides a dynamic process of combining scientific knowledge with political and social aspects. It develops opportunities to build trust, contributes to shared and informed decision making, improves adaptive governance, creates and strengthens long term relationships between stakeholders, promotes active development of new knowledge including producing preliminary research insights and findings throughout all phases of a project, and provides a constant feedback loop between science and practice and providing practitioners with science-based tools (Brugnach & Ingram 2012; Ungar & Strand 2012; Campbell et al. 2016). Co-production of knowledge and learning can contribute to the solutions of large adaptation problems (Armitage et al. 2011)

## **1.5 Integration of socio-ecological science and park management**

Protected area values are largely established by beliefs, perceptions, attitudes and actions of society (Figueroa & Aronson 2006). It is recognised that most protected areas require the cooperation and support of local communities (Wells & McShane 2004) and managing conservation in any context requires an understanding of the region's socio-ecological system and stakeholders (Knight et al. 2006a). Aligning community social values of natural areas with ecological priorities aids successful conservation (Jepson & Canney 2003; Bryan et al. 2011) and reduces uncertainty in conservation planning by considering a community's values and understanding of natural areas (Cash et al. 2003; Bryan et al. 2011).

Differing perceptions and diverse social values can be a limiting factor in climate change adaptation (Adger et al. 2009). Bennett (2016) refers to perceptions as “the way an individual observes, understands, interprets, and evaluates a referent object, action, experience, individual, policy, or outcome” and varying levels of significance society places on issues, including climate change are influenced by the values they hold (Lotze-Campen et al. 2008; O'Brien & Wolf 2010). Social values will influence how adaption to climate change will proceed, people's beliefs and values will influence how and why decisions are made, choices between adaptation options, and how resources are allocated. Even when similar values are agreed upon, there may be differences in opinion about their level of importance (Nelson et al. 2007).

As the importance of values is being realised, more studies are being undertaken to assess people's values in relation to climate change, protected areas or the natural environment (Beverly et al. 2008; Bryan et al. 2011). Research has been conducted on how people value places and landscapes (Raymond & Brown 2006; Beverly et al. 2008; Raymond & Brown 2011) which is valuable for future planning and place-based adaptation. Studies have also been carried out on park visitors and public perceptions of protected areas which aids visitor management, park governance and community education (Booth et al. 2009; Suckall et al. 2009; Buteau-Duitschaever et al. 2010). Investigations of protected area local communities and resident's perceptions have been undertaken to improve relationships and reduce conflict (Trakolis 2001; Webb et al. 2004; Allendorf et al. 2006; Allendorf 2007; Allendorf et al. 2012). Very little research has focused on local community, park neighbours and their perceptions of



protected areas in regards to climate change and park management in response to climate change impacts in order to adapt protected area management.

Studies show that more interdisciplinary research of social science based monitoring is required (Stoll-Kleemann 2010). Implementation of socio-ecological values into park management however is beginning to occur. For example, in South Africa where the development of a socio-ecological adaptive management system has brought about trust and credible relationships resulting in behavioural change in the interest of a common vision for parks (Roux & Foxcroft 2011; Freitag et al. 2014). Implementing social objectives into protected area planning however is in its initial stages and further development is required (Palomo et al. 2014; Cumming et al. 2015).

Understanding beliefs and perceptions of both park managers and the local community will assist park management such as identifying potential conflicts with local communities and neighbours or understanding the choices park managers make in response to climate change impacts. Consideration of socio-ecological factors in park management, particularly concerning climate change is an essential component to effective management and is lacking in both research and implementation.

## **1.6 Significance of research**

An uncomplicated approach directed specifically for protected area managers to assist in adapting their park management *in situ* to climate change is required. Park managers are in need of a cost effective, practical approaches to undertake basic assessment of park climate change impacts that incorporates socio-ecological aspects. The method must also be easily incorporated into an objective decision making process for adaptive management. Park planners and managers are struggling to move forward with their decision making and adaptive management for climate change because of various issues such as lack of resources, political reluctance to change, static regulatory frameworks, influence of societal structures and/or complex processes (Lemieux et al. 2011b; Geyer et al. 2015; Gorddard et al. 2016). This research will provide a method to support this change.

Substantial climate change impact research focuses on supporting protected areas ‘off-reserve’ such as identifying future locations for protected areas or connecting them on a landscape scale (Pressey et al. 2007; Hannah 2011; Gillson et al. 2013) with little attention paid to managing protected areas *in situ*. Despite considerable research of how the matrix and surrounding land uses complement and support protected areas and vice versa to produce a more resilient landscape, gaps exist in how we manage a fixed protected area and its existing values under climate change (Cumming et al. 2015; Geyer et al. 2015).

The approach of using ‘dynamic protected areas’ (as opposed to ‘fixed protected areas’) has been debated (Bengtsson et al. 2003; Rayfield et al. 2008; Andrew et al. 2014), however there are several constraints to using dynamic parks. Many areas of significant ecosystems outside current protected areas have been altered and affected by anthropogenic activities, and in many cases not ecologically viable (Andrew et al. 2014). Introducing dynamic parks requires a substantial change in managing agencies culture, including changes in legislation and policies (Runge et al. 2014). Climate change is also accelerating at a faster pace than many species can migrate to maintain sustainable populations (Santini et al. 2016).

Protected area managers will be confronted with various climate change impacts such as changes in species distribution and abundance, and altered ecosystem structures and functions. Protected areas require research, careful planning, and increasingly intensive management to minimise species loss under future climate change conditions (Peters & Darling 1985; Araújo et al. 2004; Baron et al. 2009; Griffith et al. 2009; Hole et al. 2009). The global protected area estate is at risk because few reserve management objectives have considered climate change (Hannah et al. 2002b; Schliep et al. 2008).

There is a need to bridge the gap between climate change science and socio-ecological factors and integrate into strategic level planning of protected areas (Figure 1-1) to support a higher co-production of knowledge. There is also the need to connect those elements into adapting park management for climate change with successful implementation and on-park management. There are a number of approaches being investigated by the scientific community in dealing with climate change in protected areas, however the majority of effort is at the broader level with limited impact on policy and management and a lack of implementation of knowledge or strategies at a park level (Pierce et al. 2005; Smith et al. 2006; Araujo et al. 2007; Heller &

Zavaleta 2009; Pressey & Bottrill 2009; Mawdsley 2011). The majority of research has addressed protected area systems on a regional or larger scale such as gap analysis, systematic planning and regional corridors (Game et al. 2011; Hannah 2011; Vimal et al. 2011; Groves et al. 2012; Kujala et al. 2013; Mokany et al. 2013) and conservation planning is largely about where reserves are best placed and not how they are managed.

The uncertainties associated with climate change impacts increase the need to incorporate adaptive management into park management (Rannow et al. 2014). An important component of adaptive management is monitoring and integration of research (Fischman et al. 2014). Quite often monitoring and research is *ad hoc*, does not always address management questions and issues, and does not necessarily provide practical recommendations relevant to the objectives of the park (de Koning et al. 2014; Rannow et al. 2014). There is a need for further connections between park management and monitoring, and to link that data and knowledge back into park management to support adaptive management. Simpler, clear-cut processes are required to support communication between park managers and scientists.

A range of research has been undertaken in the field of climate change in South East Queensland on adaptation (Keys et al. 2014; Shoo et al. 2014) and impacts (Kitching et al. 2011; Taylor & Kumar 2013). Existing studies include the influence of climatic changes on biodiversity and forest structures (Laidlaw et al. 2007; Kitching et al. 2011; Laidlaw et al. 2011a; Laidlaw et al. 2011b; Strong et al. 2011; Laidlaw & Forster 2012; Shoo et al. 2014). It is still unclear how protected areas in this region will be managed. The World Heritage values of the Gondwana Rainforests of Australia are susceptible to climate change, in particular the microphyll fern forests, simple notophyll evergreen vine forests, and dry rainforests with risks including higher temperatures, drought, and changes in fire regimes (Australian National University 2009). Current management of these parks needs to be adapted to better deal with climate change impacts.

## **1.7 Thesis aims and objectives**

The aim of this research is to investigate approaches to managing climate change impacts on protected areas through understanding and addressing management and planning at the park level.

### **1.7.1 Research questions**

This thesis addresses the following research questions:

1. How can socio-ecological attributes be recognised and understood as a basis for more effective protected area planning and management under climate change?
2. How can climate change impacts on protected areas be better understood at a park level?
3. How can climate change impacts and socio-ecological attributes be incorporated into decision making and adaptive management of protected areas?

## **1.8 Thesis outline**

### **1.8.1 Research process**

Figure 1-2 outlines the process applied in this thesis to answer the research questions. Research was carried out on Queensland's Gondwana Rainforests of Australia World Heritage listed protected areas in Australia.

The scope of this research is for the year 2070, climate change predictions were based on CSIRO predictions (Whetton 2011).

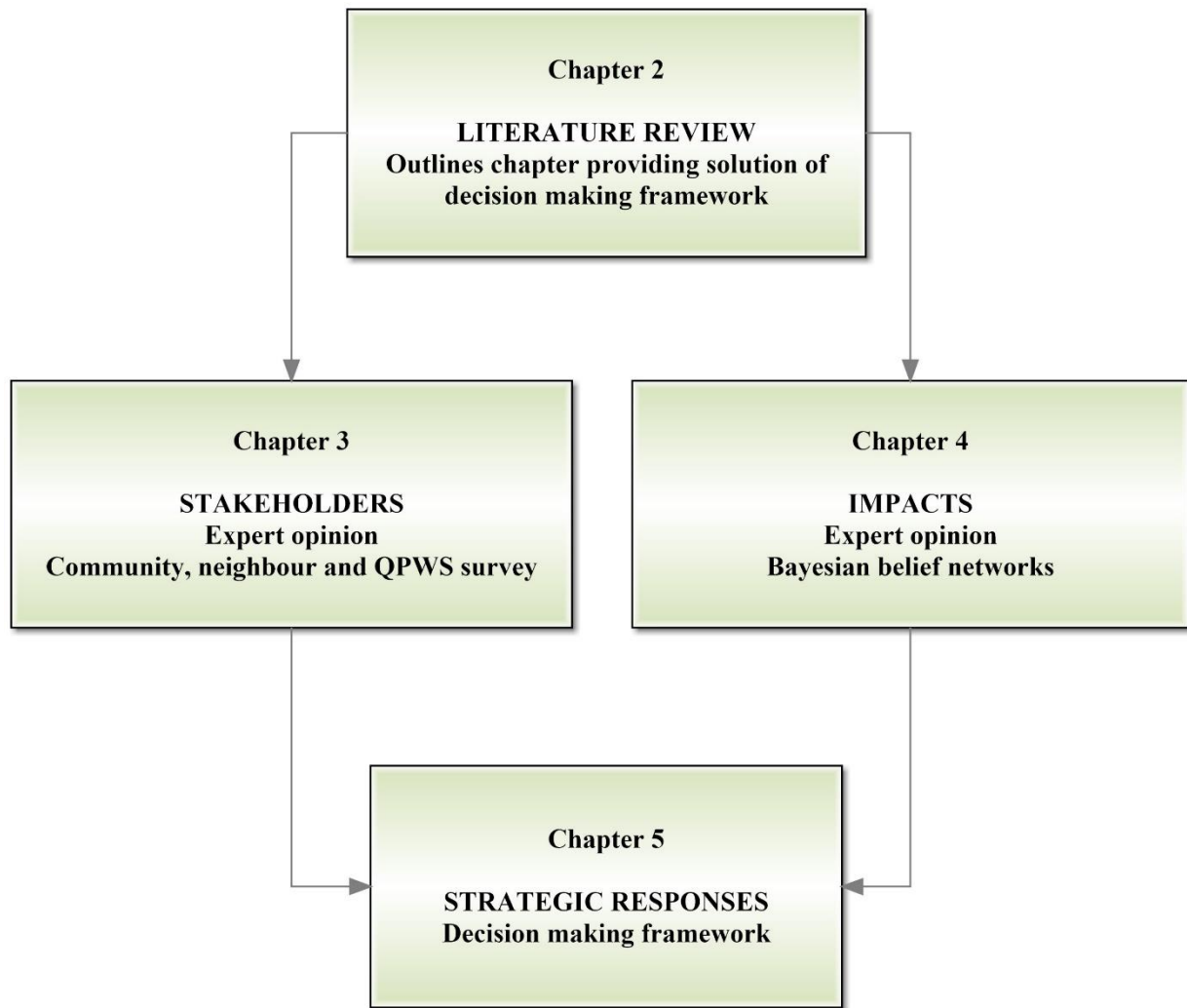


Figure 1-2 The research process for this thesis to investigate how climate change can be better incorporated into protected area management at a park level.

**1.8.1.1 Research question 1: How can socio-ecological attributes be recognised and understood for more effective protected area planning and management under climate change?**

A postal survey was carried out of the local community and protected areas neighbours to assess their perceptions of climate change impacts and park management (Chapter 3) (Dillman 1991). Surveys and interviews were conducted with Queensland Parks and Wildlife Service officers (QPWS) (Chapter 3). QPWS surveys were conducted during the interviews; the survey format was identical to the local community and neighbours to compare the views and perceptions in the region. Interviews were undertaken with national park officers to gather information on park values, threats and management. Their views on climate change impacts and management of protected areas was also collected.

**1.8.1.2 Research question 2: How can climate change impacts on protected areas be better understood at a park level?**

A set of Bayesian Belief Network (BBN) models were developed to investigate the impact and management responses under predicted climate change (Chapter 4) (Cain et al. 2000; Marcot et al. 2006). Three key values found across all four parks predicted to be impacted by climate change were investigated; stream dwelling frogs, cool temperate forests, and walking tracks. Conceptual models provided the basis for the BBNs which were developed from literature research, interviews of QPWS officers and other expert input. Collection of the conditional probabilities for models were gathered through expert elicitation. For the stream dwelling frogs and cool temperate forest models, individual interviews were conducted due to location and expert's time constraints. A workshop was conducted for the walking track models to assist QPWS officers with less scientific background and provide participants with the capacity to acquire information they may have lacked about parks they were unfamiliar with.

### ***1.8.1.3 Research question 3: How can climate change impacts and socio-ecological attributes be incorporated into decision making and adaptive management of protected areas?***

A decision making framework was developed based on the literature review (Chapter 2), interviews (Chapter 3) and the discussion with experts (Chapter 4). The model was applied to the study region with an evaluation of the model conducted by means of a workshop with planners and managers from QPWS (Chapter 5).

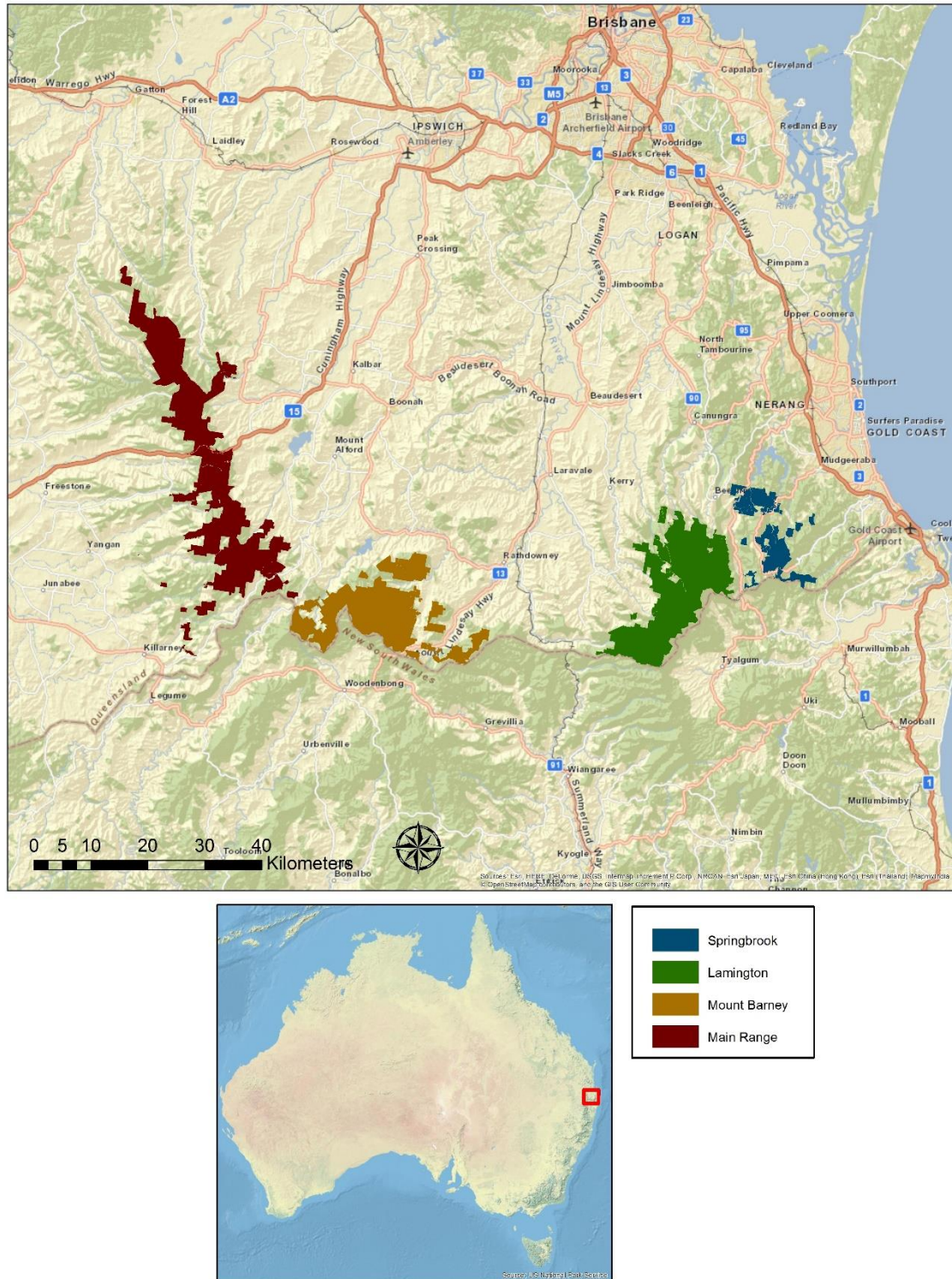
Various data analysis techniques were used throughout this thesis. Details of each technique are explained in each chapter.

## **1.9 The Study Area - The Scenic Rim**

The Scenic Rim is a mountain system in South East Queensland, Australia along the Queensland/New South Wales border, stretching from near Laidley in Queensland, south along Main Range, then eastward almost to the coast (Figure 1-3). In Queensland, it includes the Gondwana Rainforests of Australia World Heritage listed protected areas Springbrook, Lamington, Mount Barney, and Main Range National Parks.

### **1.9.1 South East Queensland climate trends and predictions**

South East Queensland is likely to become warmer with more hot days and fewer cold nights and a decline in annual rainfall, higher evaporative demand with a tendency for less run-off, more frequent and more severe droughts and altered fire regimes (Nicholls 2005; Australian National University 2009; Whitfield et al. 2010; Laidlaw et al. 2011b; Whetton 2011). In Brisbane, increases from 20.5 to 21.5 °C by 2030 and 22.1 – 23.6°C by 2070 are predicted (Whetton 2011). It is expected there will be a decrease in the mean annual rainfall, in the form of an increase in summer rainfall, but decrease in winter rainfall (Christensen et al. 2007; Christensen et al. 2013). Hail risk is expected to increase in south eastern Queensland by up to 2 days per year by 2030 and four by 2070 (Environmental Protection Agency 2008) with a 20% increase in intensity of a 1-in-100-year rainstorm (Whetton 2011).



**Figure 1-3 Location of the protected areas studied within the Scenic Rim, South East Queensland, Australia: Springbrook National Park, Lamington National Park, Mount Barney National Park, and Main Range National Park, part of the World Heritage listed Gondwana Rainforests of Australia.**



### **1.9.2 Scenic Rim Values**

The Scenic Rim's protected areas have many natural, cultural and social values in common and are rich in biodiversity (Appendix 1, Table 8-2). The Border Ranges, of which South East Queensland rainforests are part of, is one of Australia's biodiversity hotspots (Department of Environment 2015). The parks include ecological communities and species with ancient Gondwanan origins and provide primary habitat for many significant and threatened species and ecosystems, some of which are endemic to this region (Floyd 2010; Goldingay & O'Reilly 2010; Hunter 2010; Mahony 2010; Masters 2010; McDonald 2010; Metcalfe 2010; Reis 2010). The cool subtropical, warm temperate and dry rainforests, and numerous open eucalypt ecosystems provide important habitat for a diversity of primitive plant communities, and for the descendants of primitive birds such as lyrebirds and rufous scrub-birds. The parks protect over 40 frog species, many declining in numbers, over 70 mammals and about 90 reptiles which also rely on these parks for habitat (Australian National University 2009; Queensland Government 2016).

The protected areas also have significant Aboriginal and historic cultural values. There are several sites within the region that are significant to the Yugambeh, Mununjali, Githabul and Jagera Aboriginal people, including traditional pathways, burial sites, rock shelters, scarred trees, rock art, earthen rings and artefact scatters. The region also has a long history of historic values such as timber harvesting including historic sawmills, transport routes, dairy farming, sheep and cattle grazing. The parks also include historic park infrastructure such as historically registered buildings and a survey marker tree dating from Francis Roberts's 1863–65 survey that established the border between Queensland and New South Wales (Queensland Government 2011, 2013a, 2013b, 2013c).

The parks are important in providing ecosystem services to the rapid increasing human population, one of the fastest growing regions in Australia (Queensland Government 2010). Having subtropical and sub-humid climates with relatively high rainfall (Springbrook receiving over 2000 mm annually), the mountainous parks form the headwaters for over 10 catchments. Springbrook and Lamington National Parks alone protect the headwaters for five catchments including dams that supply drinking water to the Gold Coast (Queensland Government 2011, 2013c). The parks also provide visitor opportunities including bushwalking and camping, as

well as mountainous recreation such as abseiling and rock-climbing (Queensland Government 2011, 2013c, 2013b, 2013a).

### **1.9.3 Scenic Rim threats**

All four parks experience similar threats to each other. This includes introduced weeds of exotic grasses and legumes, many that were introduced as cattle pasture in the region (e.g. molasses grass *Melinis minutiflora*, vasey grass *Paspalum urvillii*, giant rat's tail grass *Sporobolus pyramidalis*, Parramatta grass *Sporobolus africanus* and groundsel bush *Baccharis halmifolia*. Riparian corridors and creek lines within the park are exposed to weeds such as crofton weed *Ageratina adenophora*, fireweed *Senecio madagascariensis*, mistflower *Ageratina riparia*, and vines such as moth vine *Araujia sericifera*, madeira vine *Anredera cordifolia*, Dutchman's pipe *Aristolochia elegans* and cats claw creeper *Macfayena unguis-cati*. Other parts of the forest ecosystem are impacted by other introduced plants such as Lantana *Lantana camara*. All the parks have exotic animals including cats, dogs, red foxes, pigs and cane toads. Other exotics recorded on park and in the region are rabbits, deer and introduced mice and rats (Queensland Government 2011, 2013c, 2013b, 2013a; Queensland Parks and Wildlife Service 2014).

### **1.9.4 Surrounding land use**

There are increasing population pressures in South East Queensland, and is intensifying demands on the area's natural assets from land clearing, development and fragmentation (Queensland Government 2009; Keys et al. 2014; Tanner-McAllister et al. 2014).

Land use surrounding the parks vary with the protected areas closer to the coast such as Springbrook having larger amounts of residential development. The western parks surrounding land uses comprise of more grazing, larger residential blocks and increasingly more hobby farmers. On the far western side of Main Range is mostly grazing with some irrigated crops.

### 1.9.5 Park management

The QPWS is responsible for the day-to-day management of the parks in accordance with the management principles for national parks as defined under Queensland's *Nature Conservation Act 1992*. Lamington National Park has an approved management plan, Springbrook, Mount Barney and Main Range have approved management statements (Queensland Government 2011, 2013c, 2013b, 2013a). Management statements and plans both outline the management intent for protected areas in Queensland. A management statement is simple document that can be prepared without public consultation and involves fewer approval stages than a plan. A management plan provides an opportunity for the public to provide input, generally as comments on a draft plan, and requires a higher level of approval (Queensland Government 1992). Both are public documents and implemented under Queensland's *Nature Conservation Act 1992*.

Queensland's Gondwana parks are managed according to key management principles from the World Heritage Convention and strategic objectives agreed to by the Australian, New South Wales and Queensland governments for the area (Department of the Environment and Heritage 2000; Department of Sustainability 2013). This means that the Australian and Queensland governments have an obligation to 'ensure that effective and active measures are taken for the protection, conservation and presentation of the cultural and natural heritage situated on its territory' and 'develop scientific and technical studies and research and to work out such operating methods as will make the State capable of counteracting the dangers that threaten its cultural or natural heritage' (UNESCO 1972). As they are World Heritage listed, the Australian Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* also governs these protected areas (Commonwealth of Australia 1999). This means that they are afforded a very high level of protection. This also ensures the public have some participation in how the protected areas are managed by legislative requirements for consultation during planning phases.

The Strategic Overview for Management of the World Heritage Central Eastern Rainforest Reserves of Australia (Department of the Environment and Heritage 2000) applies to the four parks (revised edition in preparation for the Gondwana Rainforests of Australia World Heritage). This provides an overall strategic management framework for the parks and provides the basis of management policy of the Australian, New South Wales and Queensland

governments and addresses one of Australia's obligations as State Party to the World Heritage Convention (Department of Sustainability 2013). This guides State-managed activities and therefore will also direct on-park management of the parks.

## Chapter 2

### Managing for climate change on protected areas



Plate 2 – King parrot *Alisterus scapularis*

**‘We do not inherit the earth from our ancestors, we borrow it from  
our children’ – Native American Proverb**

## 2.1 Introduction

Protected areas are one of the most effective mechanisms for achieving conservation and afford a high level of defence against biodiversity loss and environmental degradation (Geldmann et al. 2015). They require constant management and monitoring to be effective (Leverington et al. 2010; Watson et al. 2014; Coad et al. 2015; Pressey et al. 2015). Effective management of protected areas requires sound practices and an appropriate level of management and resources which may frequently be limited (Shoo et al. 2014). Climate change will make protected area management even more challenging. It is a key threatening process to biodiversity and natural systems (Krockenberger et al. 2003; Gonzalez 2010; Sommer et al. 2010) and it will exacerbate a number of already existing threats (Auld & Keith 2009). Anthropogenic climate change is having an increasing impact on biodiversity because the rate of temperature change is greater than in the past and many of the ecosystems are already under stress from other human impacts (Cooperative Research Centre for Tropical Rainforest Ecology and Management 2003; Perry 2015).

Past and current park management techniques may not be adequate for protected areas to adapt to a changing climate because parks were originally developed and managed with the notion of static boundaries and with the aim of maintaining current values (Zaccarelli et al. 2008). They have been established under assumptions that species and vegetation are relatively static (Hagerman et al. 2010a) and are generally managed *in situ* (Pressey 1994). Landscapes are dynamic and will become more so under future climate variability so therefore must be managed for change rather than static conditions (Lindenmayer et al. 2008; Wiens & Hobbs 2015). The global protected area estate is at risk because few reserve management objectives have been developed with climate change in mind (Hannah et al. 2002b).

Changes in natural systems due to climate change have been observed in many systems including the cryosphere, hydrology and water sources, coastal processes and zones, marine and freshwater biological systems and terrestrial biological systems (Rosenzweig et al. 2007). Terrestrial systems will respond in a number of ways such as species extinctions and changes in their distribution, deterioration and changes in ecosystems and ecosystem services, increases in introduced species and destruction from extreme events such as severe storms and wildfires (Cooperative Research Centre for Tropical Rainforest Ecology and Management 2003;

Rosenzweig et al. 2007; Gonzalez 2010). For example, the World Heritage listed Wet Tropics in Queensland is under extreme pressure from climate change. Studies have shown it to be very sensitive and only a 1°C increase may result in significant changes to forest ecosystems and species and possibly a significantly higher extinction rate (Hilbert et al. 2001; Ostendorf et al. 2001; Krockenberger et al. 2003; Williams et al. 2003; Meynecke 2004).

Ecosystems and species are not static, they move throughout the landscape in response to climatic changes and other influences (VanDerWal et al. 2013; Saintilan et al. 2014; Savage & Vellend 2015; Lehikoinen & Virkkala 2016). Not acknowledging this may lead to conservation goals not being achieved (Lindenmayer et al. 2008). Regional climate studies on terrestrial species have shown consistent responses to global warming including elevational and poleward range shifts (Peters & Darling 1985; Root et al. 2003; Rosenzweig et al. 2007; VanDerWal et al. 2013; Savage & Vellend 2015). For example studies have found upward elevational shifts in montane forests in Canada of around 9 m/decade due to increasing temperatures (Savage & Vellend 2015) and cloud rainforests in South East Queensland, Australia are experiencing floristic turnover and vegetation communities moving upslope in response to decrease precipitation and reduction in cloud cover (Laidlaw et al. 2011b). An analysis of 329 species in Britain found all but two species showed northward or southward movement in response to climate change (Hickling et al. 2006) and a study in Finland found that bird species are migrating northward about 1.5 km/year on average due to climate change (Lehikoinen & Virkkala 2016). Many other factors in addition to the direct impacts of climate change also play a role in species movement; climate driven processes such as fire regimes, hydrological processes, vegetation changes, introduced species, biological interactions and landscape fragmentation (Griffith et al. 2009; Bradstock 2010; Cianfrani et al. 2011).

Research shows that many animal and plant species are increasingly at risk of extinction because of climate change (Thomas et al. 2004), particularly for regions with many local endemic species (Krockenberger et al. 2003). Impacts on species with limited dispersal capabilities and/or narrow climatic tolerance ranges are highly likely to be affected because their evolutionary adaptation is slower than the rate of climate change (McCarty 2001; Cooperative Research Centre for Tropical Rainforest Ecology and Management 2003; Krockenberger et al. 2003; Auld & Keith 2009; Australian National University 2009; Thomas 2010).

Climate change has and will cause local extinctions as well as influence even a greater number species, including those not currently threatened by extinction (Urban 2015). Extinction rates are expected to increase because species habitats may change and become no longer compatible for a species physiological tolerances or may become killed from altered interactions such as predation or competition (Peters & Darling 1985; Urban 2015). A modelling exercise in south west Western Australia for example, showed high risk of declines, habitat contraction and possible extinction for many Eucalypt species from drought related environmental changes (Hamer et al. 2015).

Climate change may also present opportunities. Altered environmental conditions may increase available establishment prospects for some species to migrate beyond their current distributions (Dunlop & Brown 2008). Increases in fire frequency and intensity may provide opportunities for fire adapted species, reduction in snow cover and frost may reduce constraints on some species adapted to warmer conditions, or wetter/drier conditions may influence growth and competition (Dunlop & Brown 2008). For example, modelling of amphibians in the south eastern United States under various climate change scenarios resulted in increased refuge sites for some species (Barrett et al. 2014). This provides protected area and other natural resource managers with opportunities to manage for change (Monzon et al. 2011) to provide a positive outcome for some species and ecosystems under climate change.

## **2.2 How climate change is currently dealt with in protected area management**

### **2.2.1 Management of threats and stressors to building resilience**

Threats are ‘activities or processes that have caused, are causing, or may cause the destruction, degradation, and/or impairment of biodiversity targets’ (Salafsky et al. 2008) and it is necessary to manage threats for the ongoing protection and sustainability of protected areas. Generally, current *in situ* park management for climate change deals with threats to park values. It focuses on building a parks resilience by management of threats to reduce effects of climate change related impacts (West et al. 2009; Brown et al. 2013; Perry 2015). For example, reducing land based sources of sediment, nutrient and pesticide discharges improve a reef’s resilience and ability to recover from climate change associated impacts (Haynes et al. 2007). Protected areas will increasingly be more vulnerable as climate change introduces new threats and associated



impacts, and building resilience will enhance a protected area's ability to limit the impacts of many climate change associated threats.

Resilience, in essence, is an ecosystem's ability to absorb disturbance to maintain ecological processes and structure (Gunderson 2000; Cote & Darling 2010; Wallace 2012). In addition to threats, strategies include removing stressors to ecosystems to improve their ability to resist or recover from disturbance. Stress is a 'degraded condition of the target that results from a direct threat' (Salafsky et al. 2008). For instance, it has been identified that stresses such as sediments, land-based run-offs and increased nutrient loads increase impacts on the Great Barrier Reef such as disease, bleaching and crown of thorn outbreaks and reduce the potential for recovery after disturbances (Haynes et al. 2007; Uthicke et al. 2015). Therefore reducing additional stresses has been a focus of improving resilience of the reef under climate change (Great Barrier Reef Marine Park Authority 2014). It has been argued that resilience style approaches to management may increase vulnerability to climate change by supporting original species assemblages that increase the proportion of sensitive taxa (Cote & Darling 2010). Reaching conservation goals by maintaining resilience in some cases will be unattainable as managing those impacts will be beyond a park manager's control and/or strategies become too costly (Macgregor & van Dijk 2014).

For these reasons, protected area management may have to begin managing for change (West et al. 2009; Poiani et al. 2011). Scientists and researchers are beginning to address these problems and the topic of 'managing for change' is beginning to appear in the literature, such as setting transformative objectives and strategies (West et al. 2009; Poiani et al. 2011; Wiens & Hobbs 2015; Wyborn et al. 2016). Methods for how park managers make these decisions, incorporate them into current protected area management and implement those decisions into park management are still not well developed.

### **2.2.2 Landscape scale approaches**

Landscape fragmentation is one of the major drivers of biodiversity change and will play an important role in how biodiversity will cope under changing climatic conditions. There will be a greater loss of species under climate change than in the past because the patterns of land use in place today prohibit species migration responses to changes in climate (Higgins 2007). A species' ability to move to more suitable areas in response to climate change will be more difficult because of geographical barriers from human modification of the landscape (Krockenberger et al. 2003; Hansen & DeFries 2007; La Sorte et al. 2016). Species may not be able to adapt to site changes arising from climate change (Peters & Darling 1985) and will need to move throughout the landscape to remain within their ecological and physiological tolerance limits. Effects of climate change may be most extreme for species that have already suffered significant range contractions as a result of habitat change or harvesting (legal or illegal) and are now largely restricted to reserves such as national parks.

Hence considerable research to adapt to climate change has focused on enhancing the movement of species and ecosystems throughout the landscape in response to changing climatic conditions. A number of methods have been developed to increase landscape connectivity such as corridors, buffer zones, stepping stones, 'soft' matrixes, private conservation initiatives, and restoration (Franklin 1993; Lindenmayer & Fischer 2006) and is important when considering the establishment of protected areas and management of native habitat on other tenures.

There are a number of things to consider when using connectivity as an adaptation option to address climate change. Decreasing fragmentation may increase the distance between available habitat locations, but many species are unlikely to 'keep up with climate change' by expanding their populations through continuous habitat (Olson et al. 2009). There are also limited amounts of appropriate and environmentally diverse habitat available in landscapes already affected by land clearing practices (Hannah 2011) and what habitat is available may change over time as climate change proceeds (Groves et al. 2012).

Corridors and other systems of reducing fragmentation may produce negative effects however such as spread of diseases, introduced species and wildfire (Simberloff et al. 1992; Southwell et al. 2016). For example, the Eastern Bristlebird in Australia, a fire sensitive bird with poor dispersal abilities that is highly susceptible to large scale fires because its conservation requires areas of habitat left unburnt. Corridors may spread wildfires that pose a serious threat to the bristlebirds (Lindenmayer & Fischer 2006). Corridors can also have a negative effect by providing additional edge habitat for exotics to invade natural habitats and allow introduced species to spread from one patch to another (Hilty et al. 2006).

The cost of establishing and maintaining corridors should also be considered when compared to other options that may be more effective and cost efficient otherwise limited resources could be misused. Corridors, particularly large scale ones require substantial resources and funding. Without appropriate resources and funding, many larger scale projects require many years to implement like the Mesoamerican Biological Corridor (Spring et al. 2010). Methods are being introduced to counter this burden such as ‘least cost’ methods to generate the most efficient ecological and economic strategies (Beier et al. 2008; Cushman et al. 2009; Huber et al. 2010). Corridors do not always support species use and may not always be the most beneficial option because they can be landscape and species specific (Simberloff et al. 1992; Gilbert-Norton et al. 2010). For example, the study of the Lingue tree in Chile and Argentina found that stepping stones were more effective for its dispersal than corridors (Perez-Hernandez et al. 2015). Corridors have both advantages and disadvantages, however do not provide a solution for protected area managers adapting current approaches on-park because they are ‘off-reserve’ adaptation strategies. From a park manager’s perspective, their capacity to affect what happens outside park boundaries may be very restricted.

#### **2.2.2.1 *‘Islands’ of habitat***

Protected areas are increasingly becoming ‘islands’ of habitats in a sea of various land uses reducing resilience of parks to climate change impacts (Palomo et al. 2014). Can ‘islands’ of habitat such as isolated protected areas be more beneficial than corridors, and if so how large do they have to be and what shape makes a protected area viable in maintaining species and ecosystems.

There is no straightforward answer, there are many factors that influence at what size and shape a protected area becomes beneficial in providing adequate protection of biodiversity and other park values. In some instances, increasing the size of a habitat patch can be more beneficial than connecting up patches (Falcu & Estades 2007). Increasing a habitat patch size could be a better decision where disease, predators, invasive species or fire may utilise a corridor and threaten focal species (Simberloff et al. 1992; Falcu & Estades 2007). Smaller 'island' type habitats have the advantage of being easier to defend against introduction of new invasive species as well as managing existing introduced species (Burbidge et al. 1997). And in some cases, smaller protected areas host rare and threatened species and form a critical component of conservation because those species may not be protected anywhere else in the landscape (Richardson et al. 2015).

### **2.2.3 Systematic conservation assessment and planning**

Systematic conservation assessment is a technical approach that involves locating and organising priority areas for conservation action (Margules & Pressey 2000; Knight et al. 2006b) which is being used to determine areas suitable for protection under climate change. A systematic assessment can be completed by the use of a simple evaluation even with limited data, following the principles of representation and persistence, integrating expert input and systematic techniques, gathering and applying data that will achieve set goals, and setting both qualitative and quantifiable targets (Knight et al. 2006b).

There is an increasing number of systematic conservation planning frameworks/systems being developed (Lawler et al. 2003; Davis et al. 2006; Hortal & Lobo 2006; Ferrier & Drielsma 2010; Franklin et al. 2011) and being applied throughout the world (Araujo et al. 2007; Mikusinski et al. 2007; Reyers et al. 2007; Watson et al. 2009; Payet et al. 2010). One of the most substantial projects has been undertaken in the Cape Floristic Region in South Africa (Cowling & Pressey 2003; Cowling et al. 2003; Pyke et al. 2005). Current protected areas in the region were assessed as not being effective in protecting biodiversity under future climate change (Rouget et al. 2003; Hannah et al. 2005; Hannah et al. 2007). Systematic conservation assessment and planning has been applied to the region to address the problems of an unrepresentative reserve system of biodiversity, escalating threats to biodiversity and diminishing institutional capacity (Cowling & Pressey 2003).

Despite the considerable work on systematic planning though, problems persist at the implementation level (Pierce et al. 2005; Pressey & Bottrill 2009). Very few planning exercises have been implemented on-ground for various reasons such as lack of involvement of stakeholders including implementing agencies (Balmford & Cowling 2006). Evaluations are also still being completed at a research level having limited impact on policy and management (Araujo et al. 2007). There is limited uptake by practitioners because of perceived limitations such as complicated software, extensive data requirements, difficulty in setting targets, costs, and resulting plans often identifying unsuitable areas (Smith et al. 2006). Work is ensuing to identify these issues and others and to rectify these problems (Pierce et al. 2005; Knight et al. 2006a; Pressey & Bottrill 2008). Systematic planning is an ‘off-reserve’ strategy with the objective of understanding where future areas of conservation priority lay and has little influence on the management of currently established protected areas.

#### **2.2.4 Ecological modelling**

Ecological modelling is a process to assist scientists and natural resource managers in understanding natural systems and reducing uncertainty in decision making (Addison et al. 2013). Different models are created for varying situations and are based on some form of empirical data with a range of underlying assumptions (Wiens et al. 2009). They are extremely useful tools to estimate a variety of ecological information for the past (e.g. where species may have been or what vegetation may have been present), present (e.g. where can we currently find species) and future (e.g. how will a species respond to various climate change predictions, where will vegetation move to within the landscape) (Barnosky et al. 2003; Beaumont et al. 2005; Beaumont et al. 2007; Platts et al. 2010) which has become important for informing conservation actions.

There are many forms of ecological modelling techniques for assisting natural resource management for climate change impacts such as species distribution models (Beaumont et al. 2005; Sinclair et al. 2010) and bioclimatic modelling (Pearson & Dawson 2003; Beaumont et al. 2007). They are useful in decision making because they systematically integrate knowledge in a rational and transparent way and provide a means for exploring and resolving uncertainty (Addison et al. 2013). Models have been successfully used for environmental decision making

including the management of protected areas (Hole et al. 2009). They can vary in accuracy and be analysed in a variety of ways, therefore predictions are estimates with some degree of error, but can be very useful in filling in information gaps that may otherwise be unable to be addressed.

Modelling is a very useful tool to assist adaption of protected area management to climate change because of its ability to quantify and sometimes reduce uncertainty in decision making and provide a systematic and rational approach to decision support (Douglas & Newton 2014; Fulton et al. 2015; Stagl et al. 2015; Zomer et al. 2015). The United States National Park Service used modelling for climate change scenario planning to integrate science and management into their decision making (Cobb & Thompson 2012). Likewise, Canada's national park system has used modelling to identify climate change scenarios and potential vulnerabilities in their policy and planning frameworks (Scott et al. 2002).

It is still an area of research that has limited uptake in protected area management and decision making (Sieck et al. 2011; Addison et al. 2013). Models developed to assist decision making generally require a high level of skills or user support which make them inaccessible for park managers (Fischman et al. 2014). Addison et al. (2013) investigated possible reasons why ecological modelling is not commonly used by decision makers. They discovered that decision makers may prefer unstructured processes such as expert opinion, view modelling as resource intensive, believe modelling is too complex, and may also consider models to be inaccurate or inappropriate. The use of structured decision making can assist uptake of models by providing a suitable framing of the problem and consequences, engaging stakeholders, improving communication and building trust (Addison et al. 2013).

### **2.2.5 Incorporation of social elements into climate change adaptation**

Managing conservation in any context requires an understanding of the region's socio-ecological system and stakeholders (Knight et al. 2006a). Aligning community social values of natural areas with ecological priorities aids successful conservation (Jepson & Canney 2003; Bryan et al. 2011) and reduces uncertainty which is very much associated with climate change (Cash et al. 2003; Bryan et al. 2011).

Protected area values are largely established by beliefs, perceptions, attitudes and actions of society (Figueroa & Aronson 2006) and as the importance of values is being realised, more studies are being undertaken to assess people's values concerning the natural environment (Beverly et al. 2008; Bryan et al. 2011). It is important to have a good understanding of a protected area's community's values to ensure adaptation strategies are in accord with values and perceptions of the community but also provides practical and realistic actions for climate change adaptation for park managers. For example, Morrison and Pickering's (2013) research into the Australian snow ski industry revealed that increasing snow making was one of the primary adaptation strategies favoured by the tourism industry, however may become unfeasible as temperatures increase and water availability decreases. This is likely to lead to a conflict with conservation objectives of the parks, particularly under climate change if they require a reduction in stressors to reduce impacts.

Integrated assessment (IAs) is a commonly used method designed to deal with environmental problems by incorporating social systems with impacts, costs and benefits, and natural systems. Assessments describe possible cause-effect relationships between these factors to provide response options (Rothman & Robinson 1997; Hinkel 2005; Holman et al. 2008). They have been used in various ways to integrate climate change into different models through assessment of adaptation strategies, climate change policies, and mitigation (Ackerman et al. 2009; Patt et al. 2010; Catenacci & Giupponi 2013). IAs are not the best tool for informing policy makers on appropriate levels of adaptation because they are limited in dealing with long term forecasts that are highly uncertain; because IA models have difficulty capturing diverse climate impacts, adaptive capacity, and complexity of actors and actions (Fussel 2010; Patt et al. 2010). In addition, assessments commonly underestimate the difficulty of adaptation, consequently overestimating the benefits (Patt et al. 2010).

In addition to community values, understanding the values held by protected area managers can contribute to understanding the 'what' and 'why' of choices made by park managers in response to climate change impacts. How a protected area manager responds to climate change impacts are very much dependent on their underlying values and perception of what management objectives should be. For example, protected area management responses are influenced by their disciplinary knowledge and understanding risks to park attributes. Value judgements influence risk perception which shapes solutions to problems (Lowe & Lorenzoni

2007; Schliep et al. 2008). An assessment of protected area manager's values and perceptions can also point to potential conflicts with community and park neighbour values and perceptions.

### **2.3 Adaptive management**

Adaptive management is a method of managing natural resources using a structured approach to incorporate learning as part of the process of management, and integrated back into decision making (Williams 2011a). It has been adopted by the natural resource management community to deal with ecological and social uncertainty (Jacobson et al. 2009). The purposes of adaptive management is improvement in understanding of the natural or social system and improvement in management (Williams 2011a). It incorporates monitoring to track threats and impacts, a framework that can easily adjust management practices when necessary, and the ability to 'learn' as management is implemented which is particularly useful where there is a lack of information or data (Peterson et al. 1997; Mawdsley 2011; Scheepers et al. 2011). It supports adjustment of practices to adapt to new conditions (Arvai et al. 2006; Prato 2008; Lawler et al. 2010), and is a process to integrate scientific learning and management (Arvai et al. 2006; Gregory et al. 2006; Jacobson et al. 2006; Baron et al. 2009). It provides a way of making and acting on management decisions when there is still a lack of understanding of their potential consequences (Biggs et al. 2011b).

Adaptation to climate change can be impeded by many factors such as uncertainty in predictions, limited knowledge of future climate impacts, complexity in ecological systems, limited ecological niches, diverse values/perceptions, resources, and legislation and policy (Adger et al. 2005; Adger et al. 2009; Preston & Stafford-Smith 2009; West et al. 2009). Adaptive management is inherently reactive; due to the nature and rate of future ecological change a much more anticipatory process may be required.

Adaptive management can be passive or active (Meffe et al. 2002; Gregory et al. 2006). Active adaptive management carries out management experiments as a way of testing hypotheses (Gregory et al. 2006; Kareiva et al. 2008; Baron et al. 2009; Grantham et al. 2010) to implicitly learn from the results of the experiments. An active adaptive management approach is designed as a scientific experiment which would incorporate a control and different manipulations to test



different reactions. Active adaptive management has a limited scope better suited for a specific management problem or even a particular aspect of a problem and delivers more statistically sound results in a shorter time frame than passive adaptive management (Gregory et al. 2006). Active adaptive management is preferable because of the above reasons; however not always possible due to constraints such as lack of resources.

Passive adaptive management is generally unexpected (i.e. not developed as an experiment) (McCarthy & Possingham 2007; Williams & Jackson 2007), uses historical data to develop the best management action, initiate that action, and monitor it (Walters & Hilborn 1978; Gregory et al. 2006; Grantham et al. 2010). It has been said that passive adaptive management approaches pursue resource objectives with learning an unintended extra (Williams 2011b). It is simple and lacks experimental design (van Wilgen & Biggs 2011) and generally has a relatively slow learning potential but is low in cost (Williams 2011b). Passive adaptive management suits problems where there is a high confidence in ecosystem response because unlike active adaptive management, is not based on a scientific assessment but usually is based on a 'best guess' hypothesis where the outcome is high in confidence (Gregory et al. 2006). Nonetheless, it can be planned for with learning as an intended objective alongside management (Scheepers et al. 2011).

There are various barriers which may disrupt the feasibility of an adaptive management strategy (West et al. 2009). Lack of resources is one of the most recognised barriers (Walters 1997; Jacobson et al. 2006), particularly as adaptive management can create additional management costs. Legislation and government policies may restrict adaptive management methods (Walters 1997; Jacobson et al. 2006). Protected areas are managed and operate within government policies and legislation which may or may not be flexible enough for adaptive management strategies (Young & Lipton 2006; Scheepers et al. 2011). Various people will benefit or lose from a variety of options and therefore some strategies will not be acceptable to some (Peterson et al. 1997; Walters 1997; Jacobson et al. 2006). Particular options and strategies, despite being beneficial for many reasons may be socially unacceptable.

Adaptive management is generally a collaborative approach between scientists, managers and other stakeholders, therefore communication can be a common barrier (Gregory et al. 2006; Jacobson et al. 2006). Many recommendations forwarded by the scientific community appear to be unfeasible or impractical. This is being cited as one of the reasons why adaptive management is frequently absent in protected area planning and implementation (Hagerman et al. 2010b; Lemieux & Scott 2011). Communication is a two-way process, protected area managers need to convey their requirements and expectations which can help direct research and monitoring beneficial for protected area management objectives. Likewise, scientists and research need to transfer their knowledge back into management to achieve adaptive management. Poor communication can lead to detrimental outcomes in conservation and park management because it can lead to a breakdown in common language for expressing information and fail to cater for technical understanding. Improving communication can lead to trust, facilitate engagement and increases implementation of conservation outcomes (Addison et al. 2013).

Despite these barriers, adaptive management has begun to be successfully applied to protected area management but there are limited examples of implemented and successful adaptive management programs (Fabricius & Cundill 2014). South Africa National Parks practices an exemplary model of adaptive management that incorporates strategic monitoring (Freitag et al. 2014; Scholes 2015). Kruger National Park adopted a strategic adaptive management approach to park management in the mid to late 1990's (Freitag et al. 2014) which incorporated a socio-ecological component (Swemmer & Taljaard 2011). The approach was primarily in response to river (water), fire and elephant management issues that required a new collaborative decision making process (Pollard et al. 2011; Freitag et al. 2014). The process set a hierarchy of objectives which required monitoring and assessment to signal tipping points to reflect upper and low boundaries of acceptable variability (Rogers & Biggs 1999; Freitag et al. 2014).

Kruger National Park is proving to be successful in many aspects of systematic adaptive management with explicit objectives well accepted and committed to, increasingly stakeholder involvement, feedback loops existing at various scales, implementation of processes fairly widespread, and closer relationships being established between researchers, managers and field staff (Biggs et al. 2011b; Pollard et al. 2011). Success has also resulted in this strategic

adaptive management approach being implemented in other South African National Parks where organisational capacity has grown with greater acceptance and implementation (Freitag et al. 2014).

Using adaptive management for climate change will ensure those links are established from park management and strategic planning into climate change science. This will direct research and monitoring that is relevant and practical for planning and on-park management. It will also provide an improved understanding above what we currently know about the socio-ecological aspects when working with the local communities and park neighbours for effective adaptation to climate change impacts. The challenge though is also adapting adaptive management to deal with more significant and longer-term ecological change. Adaptation pathways, as opposed to decision-centred processes, consider the decision making processes themselves rather than the outcome and can support decision makers assess a variety of actions under high uncertainty (Wise et al. 2014). Decision making needs to be more adaptive to changing social, political and cultural environments as well as climatic variations.

## **2.4 Adaptive capacity of managing agencies (governance)**

A primary focus on adapting to climate change has been adaptively managing climate change associated impacts to target species and ecosystems and their responses with limited research on organisational capacity (Armsworth et al. 2015). Conservation policies, practices and systems themselves must also be adaptable. Effective adaptation will rely on an organisation's ability to understand and detect changes in conservation targets, how it will obtain the information it needs to do this, and how best to assess effectiveness of management activities (Armsworth et al. 2015). Managing agencies need to be flexible to respond to those changes (anticipated or unanticipated) including reallocating resources, staff skills and knowledge, and revisiting conservation goals (Armsworth et al. 2015).

Adaptive capacity is the 'ability of an individual or group to cope with, prepare for, and/or adapt to disturbance and uncertain social-ecological condition' (Armitage et al. 2011).

Adapting park management is not just about identifying strategies based on research, but an understanding of how adaptation options and strategies are constrained by social and political cultures and how they too can be adapted (Wyborn et al. 2016). Adaptation will need to be

continual and transformational in order to overcome barriers (Smith et al. 2011) and adaptation pathways provides a means for to do this. Pathways provides for a decision centred approach that highlights and focuses on the adaptive nature of the decision making process rather than being outcome focused (Wyborn et al. 2015).

Adaptive governance also concentrates on the relationship gaps between science and management (Wyborn 2015a). Co-production of knowledge contributes to the adaptive capacity of managing organisations and strong and improved knowledge exchange between scientists and decision makers is beneficial for adaptive governance structures (Cvitanovic et al. 2015).

Participatory approaches such as adaptation pathways and co-production of knowledge reduces the risk of maladaptation (Webb et al. 2013; Wise et al. 2014; Ross et al. 2015) where decision making fails to meet objectives, and may even increase vulnerability to climate change impacts (Barnett & O'Neill 2010).

## **2.5 A decision making framework for adaptation to climate change impacts for on-park management**

For this thesis, a decision making framework for adapting on-park management to climate change has been developed. For the purposes of this thesis, adaptation is an “adjustment in ecological, social or economic systems in response to observed or expected changes in climatic stimuli and their effects and impacts in order to alleviate adverse impacts of change or take advantage of new opportunities” (Adger et al. 2005). The framework (Figure 2-1) consists of three sections; context, protected area management, and management options. The context sets the foundation for clarifying the protected area system’s attributes and how they inter-relate. Protected area management addresses the aspects involved with carrying out park management. Management options include assessing possible park management strategies and determining a course of action to adapt on-park management to climate change.

### **2.5.1 Context**

Climate change and protected area management form a complex system (Lemieux & Scott 2005), and in conservation science it is important to describe the context of the system in a way that is simple, clear and provides a common understanding for all protected area managers and stakeholders (Salafsky et al. 2002). The context of the decision making framework includes investigating climate change projections and park values/threats as part of the biophysical, social and economic park structure. This is an important component of assessing climate change impacts on the protected area and to assess its vulnerability.

Vulnerability assessments are a useful tool to develop a manager's understanding of which species or systems will be affected by projected changes and why they may be vulnerable (Glick et al. 2011). Understanding vulnerability (sensitivity, exposure and adaptive capacity) of natural systems and other protected area values informs the development of effective management strategies and a critical step of climate change adaptation and planning (Rowland et al. 2011). Vulnerability assessments are being applied worldwide and in the context of protected area management to reduce uncertainty and better inform management decisions. Tools include approaches for assessing vulnerability of species, habitats, places (i.e. protected areas through to entire countries), ecosystem processes and services, water catchments, and social (Johnson 2014). Assessments are being undertaken based on ecological modelling, quantitative and empirical data; but also involve many levels of expert elicitation (Steffen et al. 2009a; Glick et al. 2011; Lee et al. 2015; Reside et al. 2016).

#### ***2.5.1.1 Climate change projections***

Forecasting probable changes in climate is an important factor in assessing climate change related impacts because predictions help develop the context and understanding of the challenges for the protected area site (Perry 2015). Although there is a degree of uncertainty associated with climate change modelling (Foley 2010), they give a general indication of how climatic elements are shifting. Predictions, together with an understanding of a park's values and threats will give protected area managers an idea of how a park may respond to climate change.

### **2.5.1.2 *Park values and threats***

Park managers require an understanding of park values in order to undertake appropriate decision making and setting management objectives for a protected area because they are the features that give it meaning and the reason/s why a park is protected (Lockwood 2006). Many parks are set aside for nature conservation and biodiversity protection, however more recently, parks are being managed for a much wider range of values (Watson et al. 2014). There are now expectations from society that protected areas will provide more than conservation, such as sustainable resource use, carbon sequestration, ecosystem services and support for local communities (Corson et al. 2014; Watson et al. 2014; Larsen et al. 2015).

Critical for management effectiveness, park values should be assessed against a full suite of threats (Salafsky et al. 2008; Wade et al. 2011) with a wide variety of these threats are relevant to climate change impacts. A good understanding of the park's threats include direct threats (e.g. invasive species, fire), indirect threats (e.g. surrounding land use) as well as underlying causes (e.g. community attitudes, values and perceptions) (Worboys et al. 2006). Some threats are more significant than others, particularly when combined with climate change such as fire and invasive species, and may require more attention.

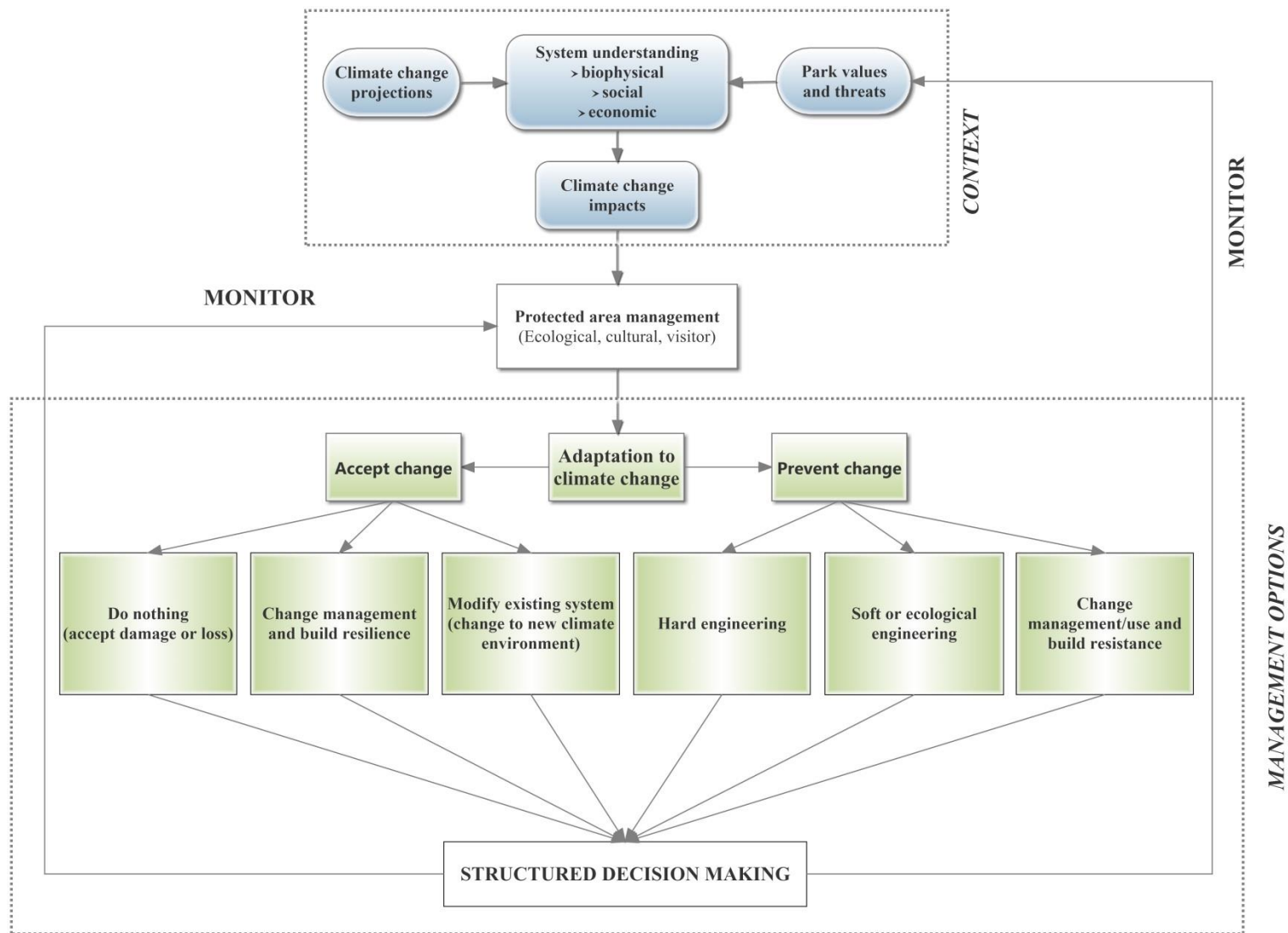


Figure 2-1 Decision making framework to assist protected area managers in managing parks for climate change impacts. Blue boxes represent the context of the park and management system, the green boxes represent the management options.

### 2.5.1.3 Fire

Fire is highly influential in many ecosystems and can be a major cause of disturbance (Lindenmayer & Fischer 2006), especially in countries such as Australia where the majority of the landscape is dominated by fire-adapted vegetation (Lucas et al. 2007). There are many factors affecting fire regimes including land use (e.g. agriculture, livestock, rural and urban development), fire management (exclusion, suppression and/or prescribed burning), vegetation type (e.g. plantations and weeds), and human influences (e.g. arson and climate change) (Shlisky et al. 2009; Liu et al. 2010).

Conflict may occur over the relative importance of values affected by fire (Penman et al. 2011). People's perceptions and values are underlying factors in protected area management decisions because personal opinions can determine objectives for park management. Consequently, one of the dilemmas managers deal with in park management is deciding on the objectives that they are managing for. For instance, the decision to maintain or increase prescribed burning with the objective to maintain open forest ecotones, or remove/reduce prescribed burning to encourage transition to closed forests/rainforest. For example, the role of fire in maintaining sclerophyll habitats adjacent to rainforest is required for many species such as the northern bettong *Bettongia tropica* and Hastings river mouse *Pseudomys oralis* whose habitat is highly dependent on these ecotones (NSW Department of Environment and Climate Change 2005; Stanton et al. 2014). Conflicts often arise over prescribed burning to maintain these sclerophyll habitats or allow natural succession of rainforest depending on personal opinions.

Research has shown there is a danger of increased fire under future climatic conditions in Australia (Lucas et al. 2007; Hasson et al. 2009) as well as other parts of the world (Flannigan et al. 2009; Liu et al. 2010). In south eastern Australia particularly, the number of very high and extreme fire danger days could increase by 4-25% by 2020 and 15-70% by 2050 (Lucas et al. 2007). Shorter intervals between fires may change ecosystems considerably and threaten biodiversity (Lucas et al. 2007). Future trends indicate that there will be major changes to Australian fire regimes, with both the direction and magnitude of these changes uncertain (Bradstock 2010). Climate change will affect fire weather scenarios in Australia by exacerbating the fire weather risk on any given day (increased frequency or intensity of extreme fire weather days) or by increasing the build-up of fire risk over a year



that may result in a longer fire season and reduction in suitable days to conduct control burning (Lucas et al. 2007). Fire is only one component of the system and fire management is a complex process interrelated with other land management aspects such as climate and invasive species (Shlisky et al. 2009).

#### **2.5.1.4 Invasive species**

Invasive species are a fundamental cause of the decline and extinction of native species. Understanding how invasive species will respond under climate change can be difficult due to the complexity of the main drivers of change, interactions with disturbance and species interactions (Thuiller et al. 2007). Invasive species can transform ecosystems, cause biodiversity loss and modify hydrological processes, amongst many other impacts (Thuiller et al. 2007; Mainka & Howard 2010). Invasive species may be affected (advantaged or disadvantaged) along every step of their invasion pathway by climate change by accelerating or impeding their initial introduction, establishment and spread (Brook 2008). Climate change may inhibit or increase populations of invasive species and hence their impacts (Hellmann et al. 2008; Gallagher et al. 2010; Sims-Chilton et al. 2010). Their traits (i.e. broad climatic tolerances, large geographic ranges, ability to survive in adverse conditions, rapid growth rates and wide dispersal) will often help them succeed in competition with native species under climate change (Hellmann et al. 2008; Mainka & Howard 2010). Many non-invasive species may invade new localities due to local extinctions and/or new favourable conditions (Steffen et al. 2009c). Research into invasive species interactions with climate change, how this impacts upon conservation values, and risk assessment is still in its initial stages (Thuiller et al. 2007; Gallagher et al. 2010; Webber et al. 2014; Roger et al. 2015).

Changes to climate could awaken ‘sleeper’ weeds and experience a sudden expansion of their range because of more suitable habitats (Campbell 2008). Other changes such as an increase in extreme events like fires and cyclones could open up areas for establishment of exotic species (Murphy et al. 2008). Environmental managers who are not aware of these potential risks may be caught unawares and be too slow to react early when management and control is more feasible (Campbell 2008; Hellmann et al. 2008; Pyke et al. 2008).

Altered fire regimes, as a result of climate change, pose a serious concern for invasive species management. Invasive, both introduced or native species outside of their existing range, are not only the least predictable of climate change impacts, but may be one of the most important of impacts that will have to be managed (Campbell 2008). There is a need to connect invasive species management with climate change and research into improving the understanding of links between climate change and invasive species (Mainka & Howard 2010). Management of invasive species under climate change will require new tools, increased monitoring, increased coordination, broader risk assessments (Hellmann et al. 2008) and provisions for systematic changes in management practice (Pyke et al. 2008).

#### ***2.5.1.5 Synergies***

A crucial issue for conservation is the ecological interactions of multiple threats and stressors, also known as synergies (Cote et al. 2016). A synergy is ‘a combined effect of multiple stressors that exceeds the sum of individual stressor effects’ (Brook et al. 2008; Cote et al. 2016). Synergistic effects increase the potential effects of invasive species for decision makers because of the unpredictability in interactions, particularly if there are multiple factors involved (Darling & Cote 2008). They are complicated because they can be cumulative in their impacts, their outcomes or interactions can be unexpected, one stressor may be more dominant than the other/s, or stressors can have the opposite effect such as pushing a system into an alternate state that is difficult to reverse (Cote et al. 2016). Synergistic relationships of current threats with climate change will likely be stronger than with other threats because their outcomes have a higher uncertainty (Brook 2008; Auld & Keith 2009). It is important to try and identify synergies so the nature of uncertainty can be characterised and it can be appropriately accommodated in decision making. Actions and strategies can then be better prioritised due to understanding which stressor or threat to act upon and where to intervene (Auerbach et al. 2015; Cote et al. 2016).

Fire and invasive species are two significant drivers of ecosystem change (Lindenmayer & Fischer 2006; Thuiller et al. 2007; Mainka & Howard 2010). Fire is a key management tool of protected areas, especially in Australia and invasive species poses a threat to biodiversity and park ecosystems (Taylor & Kumar 2013) and the two can be very closely linked. For example, experiments in the Amazon were conducted over an 8 year period to assess climate change and land use interactions with fire and grasses, both native and non-native. Results

showed increases in grass invasion following intense fires associated with drought, grasses then increased fuel loads which escalate fires (Silverio et al. 2013). An understanding of these interactions can inform decision making about where to direct management, fire and/or grasses in adapting to climate change.

In Australia, the control and removal of feral water buffalo in Kakadu National Park resulted indirectly in a reduction of small mammals (Woinarski et al. 2001; Lawes et al. 2015). Research revealed this was a result of an increase in woodlands (as a consequence in reduction of water buffalo populations) interacting with the absence of indigenous fire practices in place prior to the water buffalo introduction. Understanding these relationships resulted in a change of prescribed burning with the objective to increase small mammals (Petty et al. 2007; Lawes et al. 2015). Understanding these synergistic relationships between those drivers of ecosystem change ensured effective management strategies were implemented to reflect the appropriate outcomes of increasing small mammals. It is important to recognise that such surprises are likely to occur and seek to accommodate them. Not all are synergistic resulting in additive impacts, some are antagonistic where the combined effect is not additive. It has been shown management of local stressors can be ineffective or even degrade ecosystems where antagonisms are present (Brown et al. 2013).

Additional interactions driven or influenced by climate are expected to increase under climate change because anthropogenic climate change is increasing changes at a faster rate than historic changes (McCarty 2001). Therefore, it will be essential to pay close attention to synergistic effects in adapting protected area management for climate change. It is impossible to understand all interacting relationships because there are too many stressors to assess all of them, however identifying ecosystems, stressors and/or responses that generally interact would direct managers in the likelihood of given reactions and reduce uncertainty in park management (Cote et al. 2016).

### **2.5.1.6 System understanding**

It is important to have a thorough understanding of the biophysical, social and economic elements that the system is composed of and how they interact with each other. This provides a foundation for analysing the issues and impacts and a better understanding of how a protected area is likely to respond to climate change. This will improve a decision maker's ability in establishing objectives and management strategies by identifying and possibly reducing uncertainty, improving park threats and social assessments, exploring a wider range of options and increasing social acceptability (Biggs et al. 2011a; Bryan et al. 2011; Geyer et al. 2015; Perry 2015). There are a number of existing processes that can support understanding of complex conservation situations such as systematic assessment, environmental impact assessments, conceptual and mental models, and scenarios (Knight et al. 2006a; Worboys et al. 2006; Margoluis et al. 2009; Biggs et al. 2011a; van Vliet et al. 2012). Whichever procedure is used, it should identify the key natural, social and economic drivers of the system and establish the linkages between these variables for a full understanding of the relationships. Understanding natural and social processes and capacities decrease uncertainty in the decision making process (Fischman et al. 2014). One of the most common and effective methods is conceptual modelling (Margoluis et al. 2009).

Conceptual modelling is a useful tool in conservation planning. It helps explain complex natural systems that include diverse values, drivers and linkages (Margoluis et al. 2009), it can draw attention to the interactions between drivers and endpoints, and anticipate the major sensitivities of a system (Johnson & Weaver 2009). It provides an effective communication tool useful for stakeholder consultation (Delgado et al. 2009). Its ability to do this, as well as be updated over time and provide feedback into management makes it very compatible for adaptive management (Dale et al. 2010; Howes et al. 2010).

In developing a conceptual model to gain an understanding of an ecological system, there are many factors that need to be taken into account. A good understanding of the park, as well as the surrounding landscape is essential which will lay down the groundwork for assessing climate change impacts (Perry 2015). What are the park's features (i.e. physical elements such as size, shape and boundary), its current climatic influences, natural and cultural values, associated threats, and current condition of the park and park values? Without a good

understanding of the biophysical environment, it is difficult to predict a park's vulnerability to climate change impacts.

Effective conservation also requires an understanding of the region's socio-ecological structure. An assessment without it can be one of the limiting factors to effective planning and management (Knight et al. 2006a). Diverse social values can be a limiting factor in climate change adaptation (Adger et al. 2009). Values influence societies in terms of the different levels of significance they place on a diverse range of issues, including climate change (O'Brien & Wolf 2010). Values influence why and how decisions are made, choices of different strategies, and allocation of limited resources. Even when there is agreement on objectives of adaptation, there can still be significant differences in opinions on their level of importance, i.e. conflict occurring when it threatens another value such as lifestyle (Nelson et al. 2007). What is important enough to use limited resources on in order to maintain or improve under a changing climate? Values help define conservation objectives (Jepson & Canney 2003). For example, if we highly value a particular species, that may define objectives in maintaining or increasing that species population or habitat, which may not be possible under new climatic conditions or be resource intensive. These values will define which approach we will take in adapting to future situations.

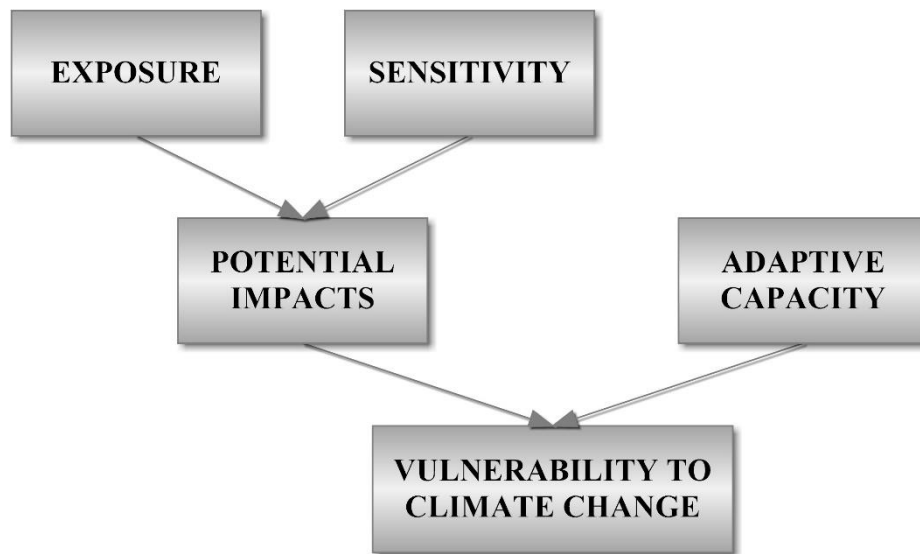
Economic factors associated with the park should be assessed and incorporated into the system understanding as they can be driving factors for many decisions. There are several elements to this such as those that have an influence on the park, for example land use changes and changing demographic patterns (McLeod et al. 2012). Alternatively, many protected areas provide substantial economic returns such as poverty alleviation, economic development, tourism and other economic contributions for society (Watson et al. 2014). It is important to think about more than just benefits derived from direct use such as tourism for example. Protected areas have also begun to be assessed for ecosystem services, the benefits that human beings gain from nature (Liquete et al. 2013). There have been various procedures to assess ecosystem services such as market based approaches (Martin-Lopez et al. 2011; Sagoff 2011; Martin-Lopez et al. 2012) and economists understand there are many values associated with the environment. There are many techniques that attempt to classify direct and non-direct uses as well as non-use values and put a monetary value on an ecosystem (Stoeckl et al. 2011). Some benefits and services are easier to quantify and clarify than others, such as tourism and fishing which are considerably easier to put a dollar value on. Other

benefits such as catchment values for clean water are harder to measure. There is a challenge in understanding the provision and value of ecosystem services (Daily et al. 2009), however is an important economic factor to consider.

#### ***2.5.1.7 Climate change impacts***

Planning for climate change requires some understanding of associated impacts to protected area values, therefore an impact assessment is required (Fischman et al. 2014). This is an assessment of how climate change effects natural systems and is based upon how vulnerable a park is due to climate change (IPCC 2014). Vulnerability assessments determine how well a park can adapt or cope with climate change (Fischman et al. 2014).

There have been a number of different meanings proposed for vulnerability (Luers 2005; Smit & Wandel 2006; Capon et al. 2013; Geyer et al. 2015), nonetheless vulnerability is a factor of exposure and sensitivity of a system to climate change events and how adaptive is the system (Figure 2-2) (Smit & Wandel 2006; Geyer et al. 2015). Exposure is the time and extent that the system is exposed to the disturbance, i.e. the climate change associated stresses (Gallopín 2006) and sensitivity, the degree to which the system is affected and will respond to given climate change (Gallopín 2006; Geyer et al. 2015). The adaptive capacity essentially is a system's ability to adjust, adapt or cope with a change in environmental conditions (Luers 2005; Gallopín 2006; Smit & Wandel 2006; Capon et al. 2013; Geyer et al. 2015).



**Figure 2-2 Components of assessing vulnerability to climate change (Ionescu et al. 2009).**

A park's characteristics, how it is placed in the landscape, and external influencing factors play a role in how values may respond to climatic changes and other threats. For instance, smaller protected areas with high boundary to area ratios struggle more against external threats and impacts (Maiorano et al. 2008; Cantu-Salazar & Gaston 2010). Smaller protected areas also have a reduced effectiveness if they are more isolated (Cantu-Salazar & Gaston 2010). In addition to size and boundary, attributes such as altitude can influence a parks response to climate change impacts. From lowland areas such as wetlands through to mountainous protected areas, distinctive parks are affected by various aspects of climate change and impacted in unique ways. For example, mountainous parks restricted through altitude are often vulnerable due to narrow environmental envelopes and geographic restrictions, and are most sensitive to increased temperatures, changes in water balance and hydrology, and extreme weather events (Laurance et al. 2011).

Questions should also be asked such as how surrounding land uses affect park values. For example, with an expected increase in fire risk, factors such as how exposed a park is with fire sensitive ecosystems need to be considered, or how does this impact fire management on a park in close proximity to residential areas? How does the park itself (i.e. size, position in the landscape, topography) influence how it will react to threats and climatic changes? Topographic position can make a park more sensitive to climatic variables such as changes in precipitation due to hydrological regimes (Capon et al. 2013) or more exposed to the surrounding land depending how it is positioned in the landscape.

Park management influences how values respond, therefore questions should be asked such as how do these affect the system, how does it interact with the projected climate change, how are these management factors influenced? For example, fire management objectives must also consider social aspects such as protection of life and property in addition to ecological objectives. In countries such as Australia that have substantial amounts of fire adapted ecosystems, this can be a crucial part of a vulnerability assessment. Fire regimes are expected to change significantly resulting in an increase in wildfire (Liu et al. 2010). For protected areas where fire regimes are required to maintain specific habitats, this may influence the parks vulnerability.

A protected area has many values with varying levels of sensitivity to climate change and a vulnerability assessment of species and ecosystems will provide a picture of the level of sensitivity of biophysical values of the park. For example, high altitude cloud forests that will find it difficult to tolerate warming and where migrating to higher altitudes is limited (Feeley et al. 2013). Particular species are more sensitive to climate variations than others with some wildlife very sensitive to direct impacts. For example, extreme temperatures of 42°C resulted in mortality of flying foxes in south eastern Australia (Welbergen et al. 2008). Other species are more sensitive to indirect impacts, for example the starvation of wild reindeer in the archipelago of Svalbard when warmer and wetter winters produced icing, reducing food availability (Hansen et al. 2014).

Vulnerability increases with greater exposure and diminishes with increasing adaptive capacity (Geyer et al. 2015). It is important to note as well that vulnerability (sources of exposure, sensitivity and adaptive capacities) operate across various scales, i.e. over time, local to global scales (Smit & Wandel 2006). Evaluating impacts gives a better understanding



of the challenges facing park management under climate change and sets the foundation for developing scenarios used for decision analysis.

### **2.5.2 Protected area management**

Once climate change impacts have been assessed, an evaluation of the park's management system in the context of this understanding is an integral part of decision making. Adaptation options must fit in with the constraints of the protected area's governance structure, planning and management systems or, where necessary and possible, these systems may need to be altered to enable effective adaptation. Managing agencies operate with governing legislation and policies and protected area management must be conducted within these directions. Consideration should also be given to their planning and operational systems, how does the managing agency manage for ecological, cultural and social values? Factors to consider include what pest and fire management systems are in place, what are the protected area's (and region's) highest priorities for fire management, what are the prominent pest issues they currently dealing with and how might priorities later with projected climate change? Likewise, for visitor management; how does the managing agency conduct visitor management; what does the region's visitor setting look like and how might these patterns change? Climate change impacts may also affect surrounding communities; who are the local Indigenous groups in the region, what is the current situation in regards to consultation and working with the local community group/s, what legislative obligations does the managing agency have? Are there non-Indigenous heritage management values that may be impacted by things such as changing fire regimes?

A description of the regional situation will be required to help inform the options for management such as species meta-populations, quality and extent of habitats and ecosystems, size and boundary of the park, influencing factors such as surrounding land use and altitudinal gradients. How might surrounding land use change with a changing climatic regime and what flow-on effects will this have for the park. Regional values will also need to be considered, such as neighbouring protected areas and their environments, i.e. do they protect similar values more suitable for climate change impacts or offer better opportunities for recreation. These factors are important when considering decisions because they provide for a wider scope of options. For instance, a species that has been assessed as having minimal sensitivity to climate change on a particular park compared to surrounding protected areas. A

first thought may be that this would be the protected area of choice to direct resources towards, however it may have a small breeding population with poorer habitat quality than a neighbouring park. These factors will influence probability of success or cost of management options.

### **2.5.3 Management options**

There have been many possible strategies put forward for adapting to climate change, some are objective focused aimed at landscape scale impacts (Gonzalez 2010; Spies et al. 2010), reducing vulnerability (Geyer et al. 2015), and species specific impacts (Gonzalez 2010; Lee et al. 2015); others are action focused by grouping strategies based on the types of actions (Mawdsley et al. 2009; Poiani et al. 2011). For the purposes of this framework (Figure 2-1), the adaptive approaches are defined as either acceptance of anthropogenic climate change impacts and attempt to adapt to a new climatic environment (i.e. do nothing, change management to build resilience, modify systems), or prevent change and attempt to maintain current systems under new climate variations (i.e. hard engineering, soft or ecological engineering, and change of management or use). Figure 2-1 demonstrates how these different approaches fit into an accept/prevent change style framework.

#### **2.5.3.1 *Accept Change***

##### **2.5.3.1.1 Do nothing**

An extreme approach that can be taken is to do nothing and accept the losses and gains that climate change will bring. This includes both undertaking no management at all and continuing to undertake current management without adaptation. This may well be a conscious decision, be due to lack of resources, or the impacts are possibly out of a park manager's control. Possibly, doing nothing is the best option, for example species that are widespread or common and thrives in various climates and habitats (Mawdsley 2011). This may also be chosen if the threat is so severe that any type of management or intervention will not change the outcome of a loss in or change of value. This action will have consequences, such as loss or gain of some species. Generally, this is not an acceptable choice as many values of protected areas are held in high regard by the public who have very strong opinions about how these values should be managed, but is a legitimate decision in itself by deciding not to act (Perry 2015). If we make a conscious decision to do nothing, this might have been a consequence of setting priorities, maybe some species will not be able to be saved no matter

what management is undertaken. Priority setting approaches such as triage (Millar et al. 2007) will be applied further in a world of limited resources and may be a necessary component of conservation policy under future climate change (Hagerman et al. 2010b).

#### **2.5.3.1.2 Change management and build resilience**

Again, the threat may be so severe that the choice may be to allow a change in that value but as slow as possible with the focus of maintaining a healthy system while the change is occurring naturally. In order to slow or reduce change, we can build resilience to enable our systems to better cope with those changes.

There are many ways to build resilience, and it is widely recognised that removing stressors and managing threats can build a system's resilience to climatic changes (Fischlin et al. 2007; Hansen et al. 2009; Lawler 2009; West et al. 2009; Mawdsley 2011; Milad et al. 2011). Carilli et al. (2009) show that resilience of bleaching events on coral sites vary with different types and levels of stress. There is some evidence that suggests this assumption is not always correct. Cote and Darling (2010) uses coral reefs to argue that management to control local stressors to restore original species assemblages may decrease an ecosystem's resilience to climate change by increasing the proportion of climate sensitive taxa. This means that levels of stress on individual ecosystems will need to be identified in order to pursue the type of management that will maximise ecosystem resilience, whether that be removing stressors and managing threats or encouraging it to change species assemblages to better cope with climate change.

#### **2.5.3.1.3 Modify existing system**

There is a strong focus for management of our natural resources on protected areas to maintain current values. Major transitions in our natural systems are expected and what managers may need to focus on is 'managing change' (West et al. 2009). The conscious decision may then need to be made to allow that system to change with management implemented to assist that change. Resilience can be built into these systems to not only slow or reduce change, but to encourage change and promote healthy and diverse ecosystems.

For instance, some conservation areas in eastern England, managers acknowledge that ecosystem changes are occurring and are designing and managing some sites in response to these future changes. One site in East Anglia has been established with grasslands in

preparation for sea level rises converting freshwater systems into salt marsh (Macgregor & van Dijk 2014). A gap exists between theory and practice in managing change (Poiani et al. 2011). To manage change, we may need to reassess our management objectives to suit a new environment such as modifying existing systems to maintain function like promoting evolution and movement.

### **2.5.3.2 Prevent change**

#### **2.5.3.2.1 Hard engineering**

If the decision is to maintain the ‘status quo’ and intervene, adaptation can be undertaken using a ‘hard’ path (Sovacool 2011) to prevent climate change affecting our lives or our functioning ecosystems that we depend upon. Hard adaptation methods, in its simplest forms may mean building levees to prevent inundation of rising sea levels for example. Shoo et al. (2011) have suggested engineering solutions to aid recovery and maintenance of amphibians under climate change. They propose examples such as installation of irrigation sprayers, retention or supplementation of natural and artificial shelters, canopy cover over ponds and creation of hydrologically diverse wetland habitats. Another example is the idea of ‘catching’ snow for snow-dependent species by building snow barriers (Price & Neville 2003).

#### **2.5.3.2.2 Soft or ecological based engineering**

Soft or ecological based engineering includes establishing or reinvigorating natural infrastructure or natural capital, as well as low impact technology (Sovacool 2011). Soft or ecological based engineering can be through assisted colonisation and restoration designed for future climate change. Some experts consider translocation of species may assist dispersal where natural migration is restricted and to establish separate populations as an insurance against extinction (McLachlan et al. 2007; Richardson et al. 2009). Under climate change where dispersal of a specific species to new areas is vital and no connecting habitat is available, this may be a viable (Hannah 2008; Lawler 2009; Loss et al. 2011) and sometimes only option. Advantages may include increasing the probability of subsequent adaptation as the climate changes, preserving low latitude species at higher latitude and altitudes as the climate changes, and assist dispersal processes that have been disrupted by loss of habitat connectivity (Hoegh-Guldberg et al. 2008; Kingsford & Watson 2011). Richardson et al. (2009) believe assisted migration should be considered an option alongside others, not just considered as a last resort.

Gene banks and captive breeding programs may ensure a species survives to establish in new areas or functioning ecosystems. Genetic conservation may lessen the impact of climate change, *in situ* (e.g. reserves) and *ex situ* (e.g. seed and tissue preservation). The Kew's Millennium Seed Bank partnership in the United Kingdom is an *ex situ* program aimed to bank seeds from around the world for the conservation of species. It targets plants and regions most threatened by climate change (Royal Botanic Gardens Kew 2011). It establishes partnerships around the world, currently around 50 countries, including Australia. One of those partnerships is with SeedQuest New South Wales which collects seeds and stores them to ensure survival of rare and threatened species (Office of Environment and Heritage 2001). In some cases, both *in situ* and *ex situ* genetic conservation has been recommended. Ahuja (2011) suggests endemic redwoods be conserved in both reserves away from their endemic locations and also in gene-banks preserving seeds, tissues, pollen and DNA.

Captive breeding programs are a protection strategy for threatened species around the world, including Australia. The mountain pygmy possum is Australia's only mammal restricted to alpine/sub alpine regions and is classified as endangered. It is highly vulnerable to climate change from disruptions to hibernation times, impacts on food sources and reduction in snow cover from warming (Department of Sustainability 2011). Brereton et al.'s (1995) model indicates the mountain pygmy possum's bioclimatic range will disappear with just a 1°C temperature increase. The captive breeding program is an insurance against species loss and maintenance of genetic variation. It aims to re-release possums back into naturally occurring rehabilitated areas (NSW National Parks and Wildlife Service 2002).

#### **2.5.3.2.1 Indirect adaptation (change management/use and build resistance)**

If the objective is to maintain an ecosystem in its current form and resist change, a change in management may accomplish this such as manipulation of fire regimes. In many countries such as Australia, fire management is an ecological tool to manage the landscape, ecosystems and biodiversity (Shlisky et al. 2009; Penman et al. 2011; van Wilgen et al. 2011). Changes in fire regimes from climate change have the ability to greatly influence our ecosystems including physical changes in moisture and drought, vegetation, ignition rates, introduced species, temperature, and landscape changes (Beer & Williams 1995; Flannigan et al. 2009; Shlisky et al. 2009; Bradstock 2010; Liu et al. 2010).

In northern Australia, a range of fire experiments were conducted in and near Kakadu National Park. Fire is a key driver of biodiversity across northern Australia (Gill et al. 2009). The research used various burning regimes to manipulate vegetation and test responses. It was found that fire affects structure and composition of savannah communities and produces a variety of responses in closed forests (Gill et al. 2009).

#### **2.5.4 Structured decision making**

High uncertainty associated with climate change presents a challenge to traditional risk-based decisions (Perry 2015) and structured decision making is a sound approach to climate change decision analysis (Fischman et al. 2014). It involves a formal process of evaluating decisions for a robust outcome (Fischman et al. 2014).

There are two possible objectives within this framework, accept change or prevent change. The question then is what is the best way to undertake management strategies to achieve either of these objectives. To gain a full understanding of all the options, an analysis of those decisions needs to be undertaken to check their viability. It is important to assess a range of objectives against a series of criteria to ensure all pros and cons are evaluated against a broad scope of options, reduce uncertainty in decision making, and understanding the risks attached to various strategies (Martin et al. 2009; Ogden & Innes 2009).

#### **2.5.5 Implementation and monitoring**

Once a decision analysis is completed, implementation and monitoring of those outcomes is essential to facilitate effective adaptive management (Linkov et al. 2006). Decision making processes can incorporate ‘learning strategies’ where there is high uncertainty (McDonald-Madden et al. 2010; Williams 2011b). Monitoring is defined as ‘the collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a conservation or management objective’ (Elzinga et al. 2001). It includes both the monitoring of long term trends in ecological responses to management interventions and assessing management effectiveness (Stem et al. 2005; Foxcroft et al. 2007).

Monitoring and scientific assessment is an important feature of the adaptive management framework (Salafsky et al. 2002). Observing indicators of change will ensure climate related changes do not go undetected (Baron et al. 2009). Climate change is altering species distributions, disturbance regimes and ecological processes at a much faster rate than in the past, and previous approaches may not be successful in the future (Groves et al. 2012). We must be ready to constantly monitor, reassess, respond to change and alter management (including change of conservation goals), change historical perspectives of biodiversity conservation, and be explicit, transparent and scientifically rigorous in treating risk and uncertainty if we are to begin to deal with climate change impacts. The framework presented in this chapter recommends monitoring park values, threats (i.e. outcome focused assessments) and effectiveness of implemented management strategies (Figure 2-1).

In a highly uncertain environment such as climate change, monitoring becomes even more important because it will provide reliable evidence of changes and understanding of different drivers of change (Rannow et al. 2014). Under climate change, it is essential to measure direct and indirect impacts on biodiversity, extent of resilience to climate change, and whether management interventions are successful (Abbott & Le Maitre 2010). Monitoring identifies changes in species populations and ecosystem structure, detects changes to baseline conditions and establishes trends (West et al. 2009; Lindenmayer et al. 2010). It allows verification of expected impacts, vulnerability assessments and model outputs to assist in future conservation planning (Abbott & Le Maitre 2010).

Detailed scientific assessment can be resource intensive, particularly for agencies with limited funding, resources and park manager skills. Baseline monitoring of key indicators should be put into place for early detection of changes, which can be a mechanism to commence rigorous scientific assessment if required. This should be incorporated into day to day park manager activities in a structured way and monitoring should be ‘outcome’ focused and linked explicitly to management responses to detect changes in values.

Monitoring assists with internal and external accountability, assessing how park strategies are going, and provides an early warning system for potential problems leading to corrective actions (Stem et al. 2005). Monitoring is now recognised as a vital component of protected area management and will guide better park management and informing management

decisions (Hockings et al. 2000; Lawler 2009; Rout et al. 2009; West et al. 2009; Blom et al. 2010; Lindenmayer et al. 2010).

## 2.6 Conclusion

There has been a considerable amount of research focused on ‘off-reserve’ strategies to support protected areas such as landscape approaches. Park managers have very limited control over external influences and management outside their protected areas. There are also advantages and disadvantages to many strategies to add to the complexity of decision making. Other approaches such as systematic planning rely on resources, availability of representative ecosystems and available properties. These however have very little assistance for *in situ* park management.

Research conducted for adapting *in situ* park management has focused primarily around dealing with threats and reducing stressors on the park and their values. The majority of park management also focuses on objectives and strategies based on past conditions. Park management requires expanding outside of historical approaches and necessitates managing for change as well.

Ecological modelling is a useful tool to support *in situ* park management in understanding natural systems and accommodate increasing uncertainty in decision making. These tools can require higher level skills than many park managers have, making them less practical.

The decision making framework approach presented here addresses many of these issues in a process practical for park managers. It integrates climate change, ecological and social knowledge to better inform decision making at a park level. It incorporates known threats and stressors (e.g. fire and invasive species) currently being dealt with. The framework provides a course to deal with park vulnerability to climate change and a means to assess a range of management options, including those of accepting and managing for changes predicted to occur to many protected areas and their values.



## Chapter 3

**Awareness and understanding of climate change impacts by local community, park neighbours and protected area managers**

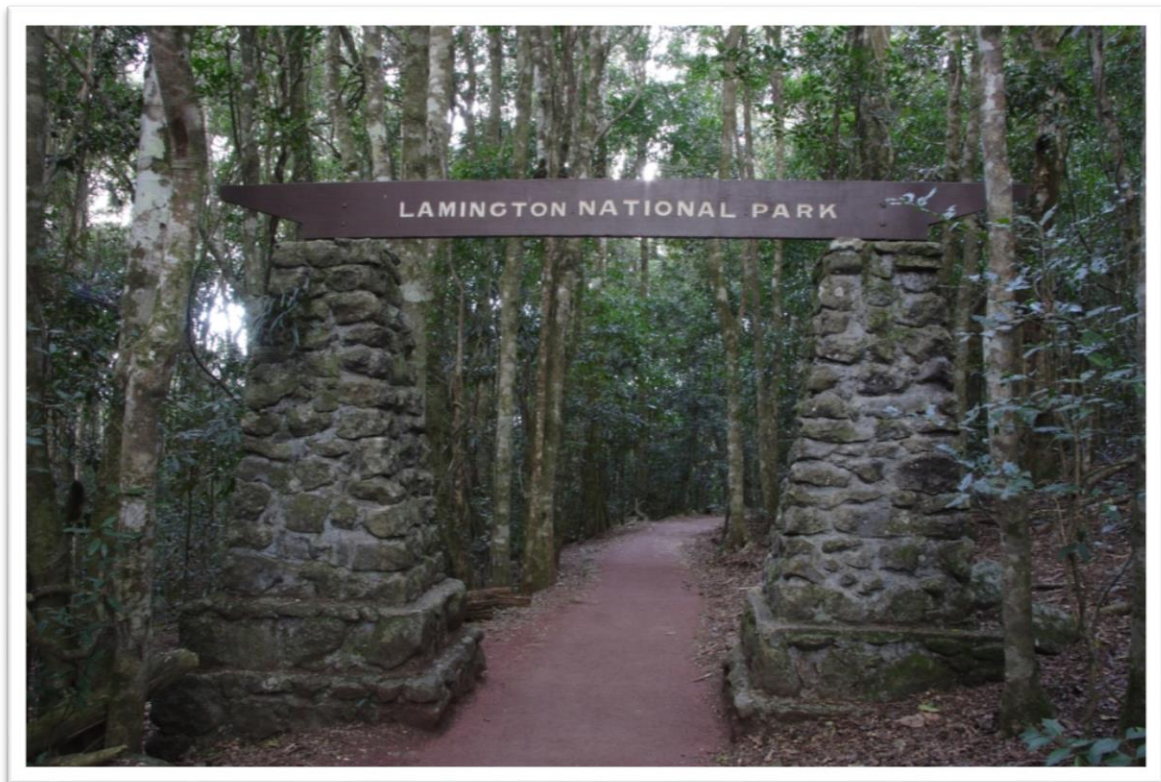


Plate 3 – Historic sign, Border track, Lamington National Park

**‘You can’t wake a person who is pretending to be asleep’ –  
Native American Proverb**

This chapter is an extension of the publication in the Australian Journal of Environmental Management published as Tanner-McAllister, SL, Rhodes, JR & Hockings, M 2014, 'Community and park manager's perceptions of protected area management: a southeast Queensland study', *Australasian Journal of Environmental Management*, vol. 21, no. 3, pp. 1-17.

### **3.1 Introduction**

Biodiversity is faced with many threats and continues to decline despite many efforts to stem this loss (Butchart et al. 2010). Creation of protected areas is one of the major strategies adopted globally to conserve biodiversity and available evidence suggests that they can be effective in many instances (Hannah et al. 2007; Geldmann et al. 2013). However, protected areas can be vulnerable in the face of global climate change (Krockenberger et al. 2003; Hannah et al. 2007; Schliep et al. 2008). Protected areas face increasing and emerging threats and impacts, and current protected area management approaches may not be adequate as climate alters (Hannah et al. 2005; Lemieux & Scott 2011). Protected areas are generally static by nature with fixed boundaries. Future species range shifts and species responses to climatic changes may modify current biodiversity patterns considerably (Hannah et al. 2007). This leads them to be particularly susceptible to climatic change impacts, such as shifts in species distributions, changes to communities, changes in breeding cycles, and environmental changes such as altered fire frequencies or stream flow regimes (Cooperative Research Centre for Tropical Rainforest Ecology and Management 2003; Baron et al. 2009; Hole et al. 2009; Rao et al. 2013).

Current conservation tools and approaches are not necessarily adequate under changing climate regimes (Mawdsley 2011), and new methods and ways of approaching park management may be required (Baron et al. 2009; Lemieux et al. 2011a). The current goals of the global protected area estate is at risk because few reserve management objectives have considered climate change (Hannah et al. 2002b; Schliep et al. 2008). Management that specifically addresses the impacts of climate change in protected areas will be imperative (Lemieux et al. 2011b). In the future, managers will need to deal with additional threats with incomplete information, which will make management choices difficult because they lie outside the experience of most park managers (Dunlop & Brown 2008). Implementing changes to protected area management however can be socially and politically challenging

(Grantham et al. 2010; Lemieux & Scott 2011) because of differences in values, ethics, attitudes, risk, and knowledge between managers, stakeholders and society. Understanding where perceptions differ between the community and park managers can facilitate socially accepted protected area decision making (Buteau-Duitschaeffer et al. 2010) and assist protected area management under future climate change.

It is recognised that management of most protected areas requires the cooperation and support of local communities (Wells & McShane 2004; Andrade & Rhodes 2012) and managing conservation in any context requires an understanding of the region's socio-ecological context and stakeholder views and perspectives (Knight et al. 2006a; Wyborn 2009). The capacity of managers to achieve desired conservation outcomes and adapt protected area management to existing and new changes can be assisted with knowledge of ecological and social values. Consideration of protected area stakeholder values and perspectives can engender a cooperative approach to management that can generate broad community support of management decisions (Grantham et al. 2010) and encourage complimentary surrounding land management practices. Identifying stakeholder commonalities and dissimilarities can also strengthen social learning and increase the success of conservation planning (Biggs et al. 2011a).

It has been argued that an understanding of human values can assist in developing conservation and park management goals (Fischer & van der Wal 2007; Robinson et al. 2012) and can be conducive to adapting management to future climatic changes (Hagerman et al. 2010a). Better connections to social values are required as many threats function at a landscape scale (Dunlop et al. 2012). Linking these values, particularly social values across the landscape in which the parks sit, can help address external influences that effect biodiversity values of the park (Borgstrom et al. 2012). It has been argued that a divergence in values can be a limitation to climate change adaptation (Adger et al. 2009). In the Australian Alps, a study of climate change adaptation has shown that even though the tourism industry, conservation managers, local government and researchers recognise that climate change is occurring, there is a conflict over adaptation options. This has ecological, social and economic consequences (e.g. use of water resources for snowmaking) (Morrison & Pickering 2013).

We examined how the community, park neighbours and park managers in the Scenic Rim region of South East Queensland perceive climate change issues. We compared the knowledge and perceptions of communities, protected area neighbours and park managers regarding climate change and park management. The aim was to identify shared and divergent views that could inform cooperative or collaborative planning for management of protected areas in the region.

It is now recognised that community, stakeholders and landscape scale management are becoming an essential part of protected area management (Franklin 1993; Halpin 1997; Lockwood & Kothari 2006; Lindenmayer et al. 2008; Franklin & Lindenmayer 2009; van Wilgen & Biggs 2011). As a result, community and stakeholder concerns and perceptions are becoming more prevalent in the use of park management and planning (Trakolis 2001; Durrant & Shumway 2004; Allendorf et al. 2006; Cihar & Stankova 2006; Allendorf 2007; Allendorf et al. 2007; Suckall et al. 2009). To gain an understanding of the key stakeholders knowledge and perceptions of climate change, protected areas and their management, a series of surveys and interviews were undertaken with the community, park neighbours and QPWS relating to this issue.

Surveys are an effective way to obtain socio-ecological data and studies have been carried out to understand public knowledge and perceptions related to climate change (Semenza et al. 2008; Hamilton & Keim 2009), biodiversity risk (Slimak & Dietz 2006) and management (McFarlane 2005). Various examples exist in the use of surveys and interviews to try and understand local community perceptions to assist protected area management (Trakolis 2001; Webb et al. 2004; Ormsby & Kaplin 2005).

Where there is a lack of knowledge or empirical data, the use of expert opinion is increasingly being sought to assist in management decisions (Lowe & Lorenzoni 2007; Kuhnert 2011). Expert opinion has been applied to various conservation problems (Hagerman et al. 2010b), and is especially useful where data is lacking or unreliable (James et al. 2010). In this regard, expert opinion has been used in various environmental areas such as species management (Al-Awadhi & Garthwaite 2006; Clark et al. 2006; Fuentes & Cinner 2010; Runge et al. 2011), ecology (Fazey et al. 2006; James et al. 2010; Gordon & Gallo 2011), policy creation (Petrokofsky et al. 2010), protected area management (Leon et al. 2003;

Yamada et al. 2003; Czembor & Vesik 2009; Wyborn 2009), and climate change (Lowe & Lorenzoni 2007; Hagerman et al. 2010b; Otto-Banaszak et al. 2011).

Expert elicitation was used to obtain information of the region's park values, threats, management, and possible climate change impacts from semi-structured interviews with protected area managers. Expert opinion was required as considerable amounts of information is still unknown. The interview questions were open ended; this allowed for unexpected information to be gathered of unknown issues which otherwise may not have been covered. They catered for more in-depth information to be gathered and provide flexibility in the interview. Face to face interviews were conducted to ensure a prompt result and ensure that answers are understood and answered in the correct context. Face to face interviews also allowed the interviewer to delve into more tailored areas of expertise (Babbie 1990; Colton & Covert 2007).

The aim was to understand:

1. What is the community's knowledge of climate change and its causes and impacts, what is their knowledge of their local protected areas and how they might be impacted by climate change, what is their perception of the quality of their management, particularly in regards to climate change impacts?
2. What is the protected area manager's knowledge of climate change and its causes and impacts, what do they believe the impacts of climate change on protected areas will be, and what do they perceive as the barriers to managing for climate change?
3. How do the perceptions and values of the community, protected area neighbours and protected area manager's compare to each other?

### **3.2 Methodology**

A postal survey was the chosen methodology because this was the most efficient means to survey the large number of participants spread across a wide geographical area required to obtain the data required. Face to face surveys and interviews were the chosen method for QPWS for the ability to delve further into responses and acquire additional information for the overall thesis.

### 3.2.1 Survey

The study employed a survey of the local community, protected area neighbours and QPWS staff (Appendix 2). The survey was designed to encourage a high response rate by including a cover letter explaining the aim of the research and its importance to the community, anonymity of the response, contact details and ethical considerations. The option was given to complete the survey digitally online or on a pre-printed form with reply-paid envelopes in order to accommodate the wide audience that includes suburban and rural communities. An incentive in the form of a competition was included to maximise response rates (Dillman 1991). Each respondent was recorded using a numbering system using letters according to the group they belonged and a number <sup>1</sup>. This was to ensure anonymity and used to examine data and reference quotes throughout this chapter.

The community sample was drawn from a random selection of postcodes of 1 242 addresses located in the four local government areas within the Scenic Rim study area. The community survey was distributed on a stratified (via protected area and postcode) random basis to ensure the surveys are distributed across the region. The study area extends from very developed, urban areas to rural, agricultural/grazing areas so a regional variation in responses was expected. This has been found to be true in other climate change perception research (Hamilton & Keim 2009). Information on postcode and basic demographics was collected to test for any regional variation in knowledge and opinions.

The response rate of 8.5% provided 105 surveys for analysis. Neighbours consisted of 161 properties directly bordering three protected areas (Springbrook, Lamington and Main Range National Parks) in the study region from postcode areas not included in the community surveys (to avoid duplication of respondents). Surveys were hand delivered to the neighbours. This yielded a response rate of 13% (n = 21). The majority of respondents were based in the Springbrook region (45% of the community and 29% of the neighbours). Survey results were representative of the broad population, as respondents were spread across income levels and education (Table 3-1). Response rates from each postal region were comparable. Each postal region had a response rate between 5.7% and 12.3% of the total number of surveys mailed to each area.

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<sup>1</sup> Each respondent is identified in this paper according to their group (C for community, N for neighbours and QPWS for park staff) and a sequential number (e.g. QPWS001)

**Table 3-1 Summary of respondent's income and educational backgrounds. Results shown as a percentage of the total number of responses from community and total number of responses from neighbours.**

|                    | Respondents      |                 |
|--------------------|------------------|-----------------|
|                    | Community        | Neighbours      |
|                    | (%)<br>(N = 102) | (%)<br>(N = 21) |
| <b>Income</b>      |                  |                 |
| <30 000            | 21.57            | 14.29           |
| 30- 60 000         | 29.41            | 23.81           |
| 60 - 90 000        | 16.67            | 14.29           |
| 90 - 120 000       | 11.76            | 14.29           |
| > 120 000          | 9.80             | 28.57           |
| N/A                | 10.78            | 4.76            |
| <b>Education</b>   |                  |                 |
| Yr 10              | 8.82             | 9.52            |
| Yr 12              | 9.80             | 23.81           |
| TAFE/diploma/Trade | 30.39            | 23.81           |
| Degree             | 44.12            | 38.10           |
| N/A                | 6.86             | 4.76            |

The surveys used Likert scales and closed/open response questions. The Likert scales and closed questions allowed for direct comparisons between the three groups. Open ended questions were used to gauge respondents' feelings or explanations when required (Babbie 1990; Colton & Covert 2007). The questions focused on the respondents' knowledge of and concerns about climate change, what they value about the natural environment, their perceptions of the significance of climate change impacts and threats on the local protected areas, as well as their views on how well local protected areas are managed. The community survey also examined the extent of interaction between respondents and protected areas while the neighbour survey examined issues of vegetation and property management.

Pre-testing and piloting surveys are an essential part of the process (Babbie 1990; Colton & Covert 2007). A pilot survey was distributed to the Glasshouse Mountains, South East Queensland, Australia. This region is a good example because it is composed of a series of mountainous protected areas within the same bio-region, within a similar distance to Brisbane and close to the Sunshine Coast, a similar situation to the Scenic Rim (i.e. Gold Coast). The pilot survey helped identify any problems or gaps with the survey questions, gave an idea of logistics, time frames, an estimate of response rates, and gave some preliminary data to test analysis techniques.

Survey results were analysed in Microsoft Excel and Statistica using statistical inference (Berenson et al. 1988). The analysis aims were to answer the following questions.

- What knowledge do the respondents have of climate change and how concerned are they?
- What impact do they perceive as the most significant?
- How do the different groups of respondents compare in their concerns and perceptions?

### **3.2.2 Interviews**

Twenty interviews were conducted with QPWS staff throughout the region (Appendix 2 and 3), consisting of 9 staff directly involved with on-ground park management (i.e. rangers, operation managers) and 11 managers/professionals (i.e. senior conservation officers, planners, managers) that had knowledge of the region. Additional questions were asked of QPWS staff regarding current values, threats, management and monitoring of parks they manage or of the Scenic Rim's protected areas. All QPWS staff approached agreed to be interviewed. This ensured that all parks in the region were covered.

Interviews were recorded and transcribed and summaries of responses were grouped together according to topic. Some of the questions delved into their perceptions and opinions on a variety of topics including adaptive management, techniques for dealing with climate change impacts, controversial topics such as assisted migration and triage, challenges and barriers to adaptive management strategies, and finally what they need to deal with climate change impacts. Some of these questions were based on the questions and findings of Hagerman et al. (2010b).



### **3.2.3 Analysis**

Differences in values and perceptions between the community, neighbours and park managers were assessed using a chi square ( $X^2$ ) test. Survey responses for climate change concern were categorised into very high, high, low and very low/no concern. Perceptions of protected area threats were categorised into high, medium and low impact and park management from very good to very poor quality. Although response rate was lower than desired, the data are sufficient to compare using chi square analysis (Fowler & Cohen 1990). Very good and good were combined to improve analysis, as were very poor and poor.

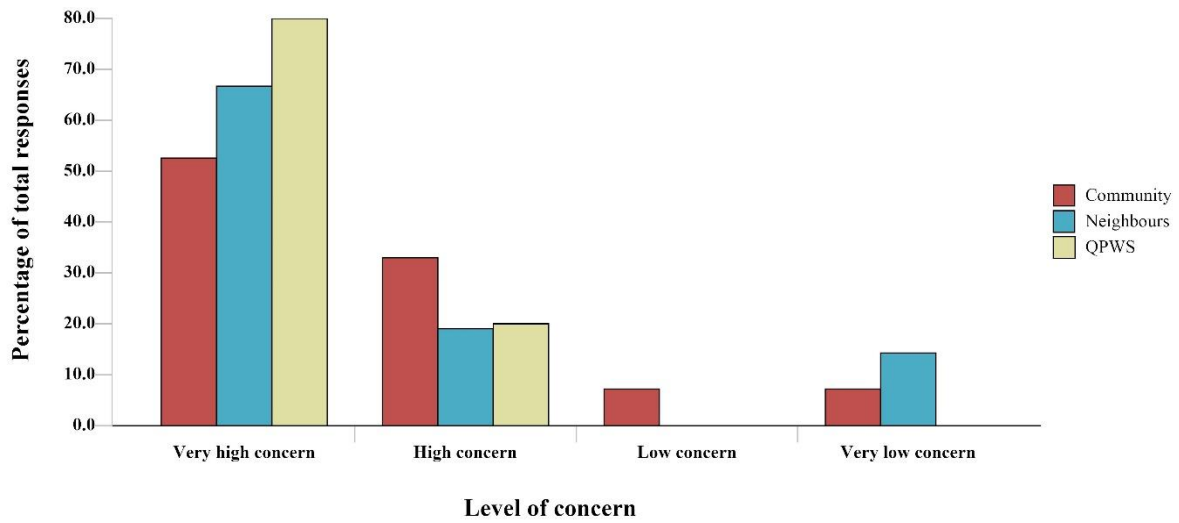
A cluster analysis was undertaken using PATN software (Belbin & Collins 2009) to identify any emergent groupings within the dataset, across all three groups. A row fusion dendrogram was produced to determine the optimum number of respondent groups.

## **3.3 Results**

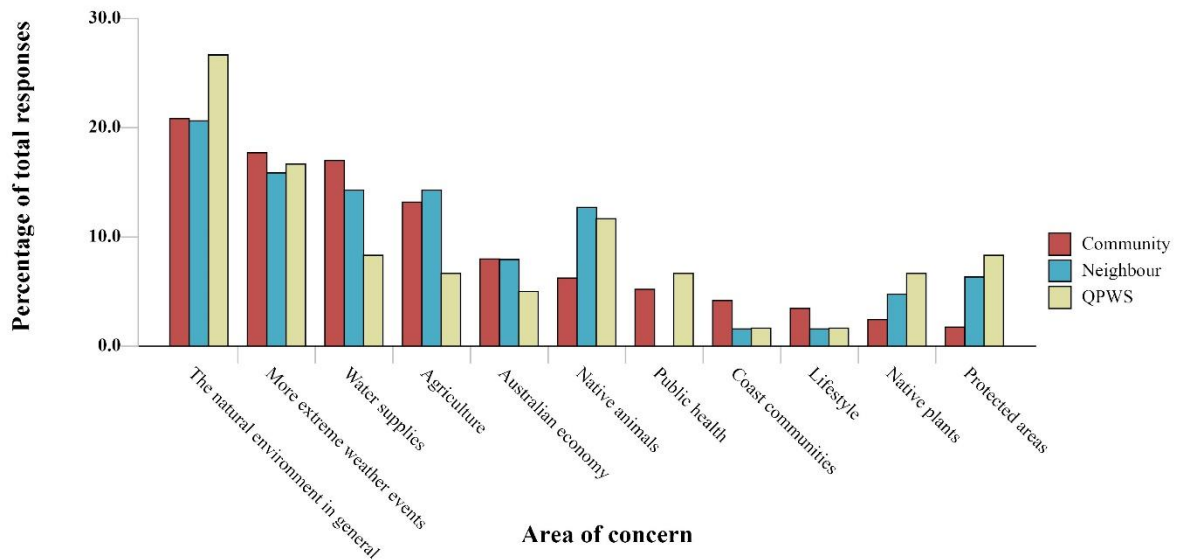
### **3.3.1 Perceptions of climate change and park threats and impacts**

Most respondents were very highly or highly concerned about climate change (86% of community, 86% of neighbours and 100% of QPWS), with no significant difference between the groups (Figure 3-1).

A high proportion of respondents ranked the natural environment as one of their highest concerns about climate change. There was a significant difference between QPWS and neighbours ( $p = 0.02$ ,  $df = 10$ ) and QPWS and community ( $p = 0.035$ ,  $df = 10$ ) in other areas of concern. Although there was no significant difference between the three stakeholder groups, the community and neighbours shared concern about water supplies, agriculture and the Australian economy, while QPWS staff were less concerned about these topics. QPWS and neighbours had similar concerns about native plants/animals and protected areas, while these issues were less concerning to the general community (Figure 3-2).



**Figure 3-1** Bar graph depicting concern about climate change issues for community (n = 97), protected area neighbours (n = 21), and QPWS staff's (n = 20) in the Scenic Rim (percentage of total responses).



**Figure 3-2** Bar graph depicting what the community (n = 97), protected area neighbours (n = 21), and QPWS staff's (n = 20) were most concerned about in the Scenic Rim (percentage of total responses).

The community and neighbours differed significantly from QPWS about the level of concern of park impacts (Table 3-2). The community and neighbours considered recreational activities and large temperature changes as a lower impact. They believed introduced animals were a higher impact. QPWS considered energy production and mining as a lower impact. The community and neighbours were split between high (33% and 44% respectively) and low (57% and 42% respectively). The community also perceived residential and commercial development impacts significantly more highly than QPWS staff. Furthermore, the neighbours perceived inappropriate management as either high impact (59%) or low impact (35%), while QPWS considered it more a medium impact. The neighbours also considered storms and flooding and collecting plants as a lower impact than QPWS (Table 3-2).

Introduced animals were seen as a significantly lower threat by QPWS staff than the community and neighbours (Table 3-2). The community and neighbours both believed introduced animals would have a higher impact under climate change. The closer people lived to a protected area, the greater the perception of the significance of the threat and impacts of feral species. Within the community group, there were significant differences in the perception of feral species impacts ( $\chi^2 = 18.38$ ,  $p = 0.003$ ,  $df = 5$ ) and how they are managed ( $\chi^2 = 25.13$ ,  $p = 0.03$ ,  $df = 14$ ) according to the distance they lived from their closest park. Community members living closer to parks consider feral animals to be a greater threat and to be more poorly managed than the general community living further away from parks (Table 3-3 and Table 3-4).

Community, neighbours and QPWS all agreed that weeds are a medium/high threat (93% of community, 90% of neighbours and 100% of QPWS), that their impact would be significant (81% of community, 79% of neighbours and 95% of QPWS), and that they were currently managed either poorly or only averagely well (74% of community, 81% of neighbours and 72% of QPWS).

**Table 3-2 Perceptions of the Scenic Rim's threats and impacts under climate change on the Scenic Rim's protected areas. Chi square was used to test for significant differences between the community, park neighbours and QPWS staff responses. Results shown as a percentage of total number of responses. Column  $x^2, p$  (df 5) indicates significant ( $p < 0.05$ ) difference between the groups of respondents.**

|  | Community<br>(N = 94) |            |            | Neighbours<br>(N = 21) |            |            | QPWS<br>(N = 18) |            |            | $x^2, p$ (df 5)          |                    |                     |
|--|-----------------------|------------|------------|------------------------|------------|------------|------------------|------------|------------|--------------------------|--------------------|---------------------|
|  | High<br>(%)           | Med<br>(%) | Low<br>(%) | High<br>(%)            | Med<br>(%) | Low<br>(%) | High<br>(%)      | Med<br>(%) | Low<br>(%) | Community/<br>Neighbours | Community/<br>QPWS | Neighbours/<br>QPWS |
| THREATS                                |                       |            |            |                        |            |            |                  |            |            |                          |                    |                     |
| Energy production and mining           | 33                    | 10         | 57         | 44                     | 0          | 56         | 21               | 37         | 42         | 12.33, 0.031             | 17.45, 0.004       | 17.5, 0.004         |
| Recreational activities                | 18                    | 43         | 40         | 16                     | 37         | 47         | 20               | 75         | 5          |                          | 15.33, 0.009       | 15.87, 0.007        |
| Inappropriate management               | 32                    | 35         | 33         | 59                     | 6          | 35         | 35               | 45         | 20         |                          |                    | 13.61, 0.018        |
| Large temperature changes              | 27                    | 41         | 33         | 42                     | 26         | 32         | 60               | 25         | 15         |                          | 13.89, 0.016       | 12.05, 0.034        |
| Storms and flooding                    | 11                    | 43         | 46         | 21                     | 21         | 58         | 20               | 60         | 20         |                          |                    | 13.65, 0.018        |
| Introduced animals                     | 56                    | 33         | 11         | 67                     | 22         | 11         | 30               | 65         | 5          |                          | 12.80, 0.025       | 14.3, 0.014         |
| Residential and commercial development | 26                    | 30         | 44         | 26                     | 32         | 42         | 30               | 55         | 15         |                          | 12.01, 0.035       |                     |
| Fragmentation of native vegetation     | 36                    | 34         | 30         | 33                     | 56         | 11         | 55               | 40         | 5          |                          | 11.49, 0.042       | 12.19, 0.032        |
| Collecting plants                      | 20                    | 34         | 46         | 16                     | 10         | 74         | 5                | 30         | 65         |                          |                    | 11.18, 0.048        |
| Fire and fire management               | 37                    | 47         | 16         | 47                     | 32         | 21         | 45               | 55         | 0          |                          |                    |                     |
| Weeds                                  | 54                    | 39         | 7          | 65                     | 25         | 10         | 55               | 45         | 0          |                          |                    |                     |
| Hunting and collecting animals         | 15                    | 27         | 58         | 22                     | 17         | 61         | 21               | 37         | 42         |                          |                    |                     |
| Transportation corridors (e.g. roads)  | 17                    | 35         | 48         | 16                     | 26         | 58         | 15               | 60         | 25         |                          |                    |                     |
| Dams and water management/use          | 17                    | 36         | 47         | 16                     | 21         | 63         | 5                | 50         | 45         |                          |                    |                     |
| Logging and wood harvesting            | 15                    | 18         | 67         | 22                     | 17         | 61         | 10               | 20         | 70         |                          |                    |                     |
| Agriculture                            | 10                    | 32         | 58         | 10                     | 20         | 70         | 10               | 50         | 40         |                          |                    |                     |

|   |    |    |    |    |    |    |    |    |    |              |             |              |
|---|----|----|----|----|----|----|----|----|----|--------------|-------------|--------------|
| Illegal human activities (vandalism, trailbikes)                  | 29 | 41 | 30 | 32 | 42 | 26 | 15 | 60 | 25 |              |             |              |
| Geological events (e.g. landslides)                               | 22 | 51 | 28 | 28 | 50 | 22 | 5  | 65 | 30 |              |             |              |
| Utility services (e.g. powerlines)                                | 13 | 42 | 45 | 28 | 33 | 39 | 10 | 53 | 37 |              |             |              |
| Fishing   | 3  | 19 | 78 | 6  | 24 | 70 | 5  | 21 | 74 |              |             |              |
| Drought   | 30 | 38 | 32 | 17 | 38 | 45 | 40 | 45 | 15 |              |             |              |
| Pollution   | 23 | 43 | 34 | 25 | 40 | 35 | 30 | 50 | 20 |              |             |              |
| Changes in habitat from climate change                            | 39 | 33 | 28 | 37 | 42 | 21 | 58 | 26 | 16 |              |             |              |
| IMPACTS   |    |    |    |    |    |    |    |    |    |              |             |              |
| Change in breeding times for animals                              | 36 | 36 | 28 | 72 | 11 | 17 | 64 | 31 | 5  | 14.26, 0.014 | 12.1, 0.033 | 14.93, 0.011 |
| Increase in feral animals   | 46 | 31 | 23 | 75 | 5  | 20 | 50 | 30 | 20 | 12.0, 0.035  |             |              |
| Local extinction of native animals                                | 44 | 28 | 28 | 62 | 19 | 19 | 72 | 28 | 0  |              |             |              |
| Local extinction of native plants                                 | 47 | 28 | 25 | 62 | 19 | 19 | 61 | 39 | 0  |              |             |              |
| Change in vegetation types  | 50 | 28 | 22 | 62 | 19 | 19 | 80 | 20 | 0  |              |             |              |
| Increase in weeds   | 53 | 28 | 19 | 68 | 11 | 21 | 75 | 20 | 5  |              |             |              |
| Change in flowering times in plants                               | 42 | 33 | 26 | 65 | 10 | 25 | 67 | 33 | 0  |              |             |              |
| Restriction of plant and animal movement throughout the landscape | 41 | 37 | 22 | 57 | 19 | 24 | 61 | 39 | 0  |              |             |              |

**Table 3-3 How well community perceived feral animals as a threat to protected areas in the Scenic Rim according to the distance they lived to their closest park. Results extracted from the community surveys only (i.e. neighbour surveys excluded), results shown as a percentage of the total of responses from each distance group.**

|                       |         | Threat      |               |            |
|-----------------------|---------|-------------|---------------|------------|
|                       |         | High<br>(%) | Medium<br>(%) | Low<br>(%) |
| Distance<br>from park | < 1 km  | 6.25        | 75            | 18.75      |
|                       | 1-10 km | 62.86       | 31.43         | 5.71       |
|                       | > 10 km | 41.18       | 35.29         | 23.53      |

**Table 3-4 How well community perceived feral animals were managed on protected areas in the Scenic Rim according to the distance they lived to their closest park. Results extracted from the community surveys only (i.e. neighbour surveys excluded), results shown as a percentage of the total of responses from each group according to distance.**

|                     |           | Management       |             |                |             |                  |
|---------------------|-----------|------------------|-------------|----------------|-------------|------------------|
|                     |           | Very good<br>(%) | Good<br>(%) | Average<br>(%) | Poor<br>(%) | Very poor<br>(%) |
| Distance to<br>park | < 1 km    | 5.71             | 8.57        | 34.29          | 17.14       | 34.29            |
|                     | 1 – 10 km | 9.1              | 15.15       | 27.27          | 24.24       | 24.24            |
|                     | > 10 km   | 20               | 46.67       | 20             | 6.66        | 6.67             |

### 3.3.2 Perceptions of protected area management

The community, neighbours and QPWS perceive the management of threatened species significantly differently (Table 3-5). Neighbours tend to disagree more with QPWS than the community. The neighbours have more significant differences with QPWS in how they perceive park threats, impacts and management (Table 3-2 and Table 3-5).

On the Scenic Rim, it appears fire management issues emanate from people's beliefs and ideals about the desired state of ecosystems, evidenced by the contentious issue of whether to burn to maintain open eucalypt ecosystems or allow rainforest succession. Although no significant differences could be found, it was evident from QPWS interviews that fire is a contentious issue.

‘ARCS [Australian Rainforest Conservation Society] and the rainforest community... have a heavy influence on our fire management to the extent where they want to see it all turn to rainforest in open forest areas’ (QPWS04).

Also, surrounding land uses are perceived to be imposing fire changes to park management.

‘Bed-and-breakfast places are springing up near Lamington, Mt Barney and Main Range, so you're getting a change in adjacent land use from traditional grazing type land management to more lifestyle blocks, so you're getting changes to fire management regimes... the lifestyle or the B&B owners are probably less likely to undertake prescribed burning than graziers, so you are getting changes to the bushfire hazards in adjacent areas’ (QPWS20).

‘there's places up there that can't be burnt because housing developments have been put in a way that you cannot burn the landscape and ensure it doesn't leave our park’ (QPWS05).

This can sometimes contradict species and ecosystem management.

‘We very rarely ever get down to doing a conservation burn based on real science or real outcomes, other than protecting neighbours and infrastructure and the like’ (QPWS22).

‘We've seen some fires encroach into some rainforest areas in the last couple of decades, namely Lamington and Springbrook. I never thought I'd see burning through rainforest, but it does happen and that's got to have a dreadful effect on native plants and animals and biodiversity’ (QPWS11).

**Table 3-5 Perceptions of how well Scenic Rim protected area attributes are currently managed. Chi square was used to test for significant differences between the number of community, park neighbours and QPWS responses. Results shown as a percentage of total number of responses. Very good and good were combined to show the differences clearer, as were poor and very poor. Column  $\chi^2, p$  (df 9) indicates those with significant ( $p < 0.05$ ) difference between the groups of respondents.**

|                                    | Community<br>(N = 80) |             |                       | Neighbours<br>(N = 19) |             |                       | QPWS<br>(N = 19)      |             |                       | $\chi^2, p$ (df 2)       |                    |                     |
|------------------------------------|-----------------------|-------------|-----------------------|------------------------|-------------|-----------------------|-----------------------|-------------|-----------------------|--------------------------|--------------------|---------------------|
|                                    | Good/very<br>good (%) | Average (%) | Poor/very poor<br>(%) | Good/very<br>good (%)  | Average (%) | Poor/very poor<br>(%) | Good/very<br>good (%) | Average (%) | Poor/very poor<br>(%) | Community/<br>Neighbours | Community/<br>QPWS | Neighbours/<br>QPWS |
| Pollution                          | 52                    | 34          | 14                    | 59                     | 35          | 6                     | 22                    | 44          | 34                    |                          | 6.83, 0.03         | 7.84, 0.02          |
| Threatened species                 | 43                    | 42          | 15                    | 18                     | 35          | 47                    | 21                    | 26          | 53                    | 9.19, 0.01               | 11.61, 0.003       | 10.9, 0.004         |
| Fire                               | 43                    | 36          | 21                    | 32                     | 42          | 26                    | 57                    | 32          | 11                    |                          |                    |                     |
| Weeds                              | 26                    | 32          | 42                    | 19                     | 43          | 38                    | 28                    | 17          | 55                    |                          |                    |                     |
| Water                              | 45                    | 38          | 17                    | 24                     | 47          | 29                    | 29                    | 53          | 18                    |                          |                    |                     |
| Feral animals                      | 29                    | 29          | 42                    | 22                     | 22          | 56                    | 32                    | 32          | 36                    |                          |                    |                     |
| Commercial tourism                 | 37                    | 44          | 19                    | 39                     | 33          | 28                    | 45                    | 33          | 22                    |                          |                    |                     |
| Illegal human activities           | 37                    | 37          | 26                    | 32                     | 32          | 36                    | 48                    | 47          | 5                     |                          |                    |                     |
| Fragmentation of native vegetation | 40                    | 40          | 20                    | 31                     | 44          | 25                    | 29                    | 35          | 36                    |                          |                    |                     |
| Recreation                         | 40                    | 40          | 20                    | 36                     | 41          | 23                    | 42                    | 42          | 16                    |                          |                    |                     |



### 3.3.3 Cluster analysis

Three clusters were distinguishable from the cluster analysis. The first comprised the majority of the respondents (64%). Described as ‘very concerned’, they represented a group of people who believed highly in anthropogenic climate change and that it was having a highly significant impact on the environment, both globally and locally (Table 3-6). A large percentage of the community (58%), neighbours (78%) and QPWS (79%) fell into this group.

The second cluster can be described as ‘concerned’ (29% of respondents) and signified a group that believed in anthropogenic climate change and that it was having a reasonable impact on the environment both globally and locally (Table 3-6). Included in this group were 33% of the community, 11% of neighbours and 21% of QPWS.

The third cluster, portrayed as ‘least concerned’ (8% of respondents), believed human induced climate change was less significant. They considered both global and local impacts on the environment as considerably lower. The remaining 9% of the community and 11% of neighbours were in this group, with no QPWS respondents. There was no significant difference between clusters in terms of income ( $\chi^2 = 13.349$ ,  $p = 0.1004$ ,  $df = 8$ ), level of education ( $\chi^2 = 2.9939$ ,  $p = 0.8096$ ,  $df = 6$ ), or how close they lived to a protected area ( $\chi^2 = 3.539$ ,  $p = 0.0472$ ,  $df = 4$ ).

The ‘very concerned’ cluster rated all park threats higher than the other clusters. The ‘concerned’ group rated park threats as lower than those who were ‘very concerned’, but higher than the ‘least concerned’ group (Figure 3-3).

**Table 3-6 Cluster means of climate change causes, significance of global impacts of climate change, and significance of local impacts of climate change (0 - no significance, 5 - very high significance).**

|                                 | <b>Clusters</b>               |                       |                                |
|---------------------------------|-------------------------------|-----------------------|--------------------------------|
|                                 | Very<br>concerned<br>(N = 74) | Concerned<br>(N = 26) | Least<br>concerned<br>(N = 15) |
| <b>Causes</b>                   |                               |                       |                                |
| Land clearing                   | 4.9                           | 4.6                   | 2.3                            |
| Coal and oil                    | 4.9                           | 4.4                   | 1.4                            |
| Pollution                       | 4.7                           | 3.9                   | 1.8                            |
| Ozone layer change              | 4.3                           | 3.5                   | 1.5                            |
| Methane emissions               | 4.0                           | 3.2                   | 1.1                            |
| Natural gas                     | 3.9                           | 2.9                   | 1.4                            |
| Landfill                        | 3.6                           | 2.6                   | 1.1                            |
| Agricultural practices          | 3.4                           | 2.9                   | 0.8                            |
| <b>Global impacts</b>           |                               |                       |                                |
| Icecap melting                  | 5.0                           | 4.4                   | 1.6                            |
| Increase global temperature     | 4.9                           | 4.3                   | 1.4                            |
| Glacier melting                 | 4.9                           | 4.1                   | 1.2                            |
| Sea temperatures                | 5.0                           | 4.3                   | 1.8                            |
| Food production and security    | 4.8                           | 4.4                   | 1.9                            |
| Increase in sea level           | 4.7                           | 4.2                   | 1.3                            |
| Decrease in snow                | 4.7                           | 3.8                   | 1.3                            |
| Changes in ocean salinity       | 4.6                           | 3.8                   | 1.5                            |
| Increase in floods              | 4.6                           | 4.0                   | 1.3                            |
| Water quality/quantity          | 4.5                           | 4.0                   | 1.3                            |
| Fire frequency and intensity    | 4.5                           | 3.9                   | 1.0                            |
| Increase in drought             | 4.6                           | 4.2                   | 1.7                            |
| Changes in rainfall             | 4.5                           | 4.1                   | 1.3                            |
| Extreme weather events          | 4.4                           | 4.2                   | 1.3                            |
| Longer/colder winters           | 3.8                           | 3.3                   | 1.3                            |
| <b>Local impacts</b>            |                               |                       |                                |
| Increase in weeds               | 4.6                           | 3.7                   | 0.7                            |
| Local extinction plants         | 4.5                           | 3.4                   | 0.4                            |
| Local extinction animals        | 4.5                           | 3.4                   | 0.4                            |
| Flowering times                 | 4.4                           | 3.4                   | 0.7                            |
| Restriction of species movement | 4.4                           | 3.4                   | 0.9                            |
| Increase in feral animals       | 4.4                           | 3.3                   | 1.2                            |
| Change in vegetation types      | 4.4                           | 3.6                   | 0.5                            |
| Breeding times                  | 4.2                           | 3.1                   | 0.6                            |

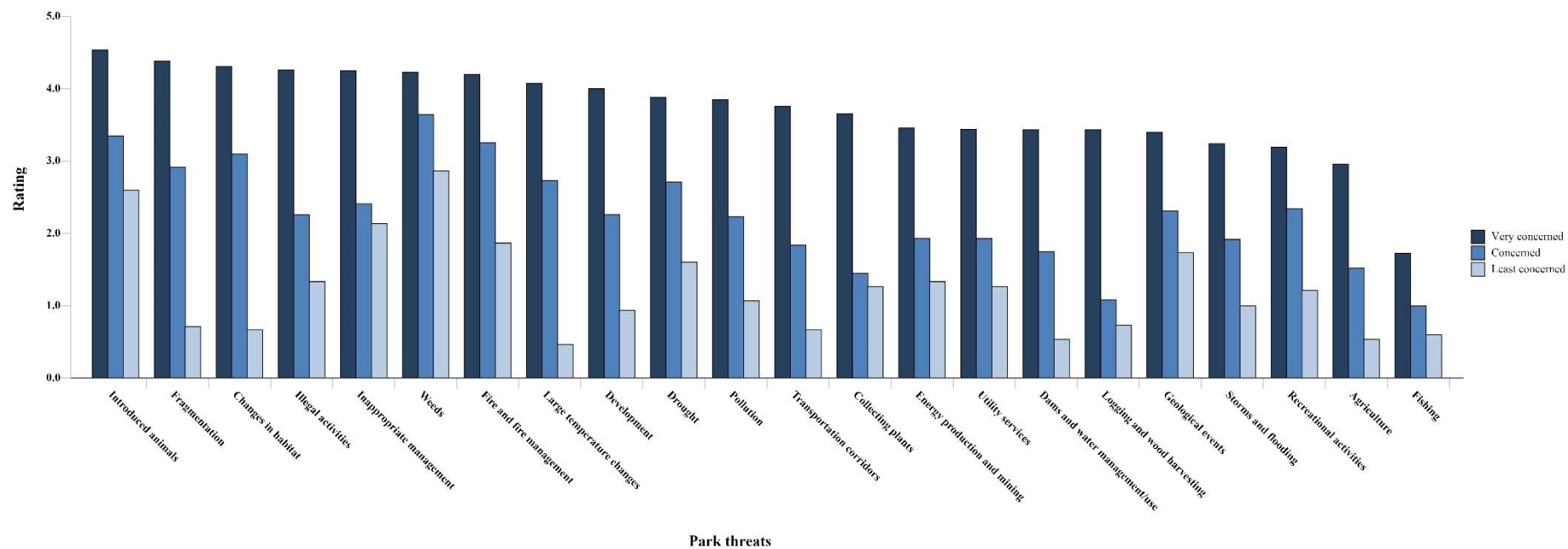


Figure 3-3 Cluster means of how the respondents rated perceived significance of local park threats under climate change (0 - no threat, 5 - very high threat).

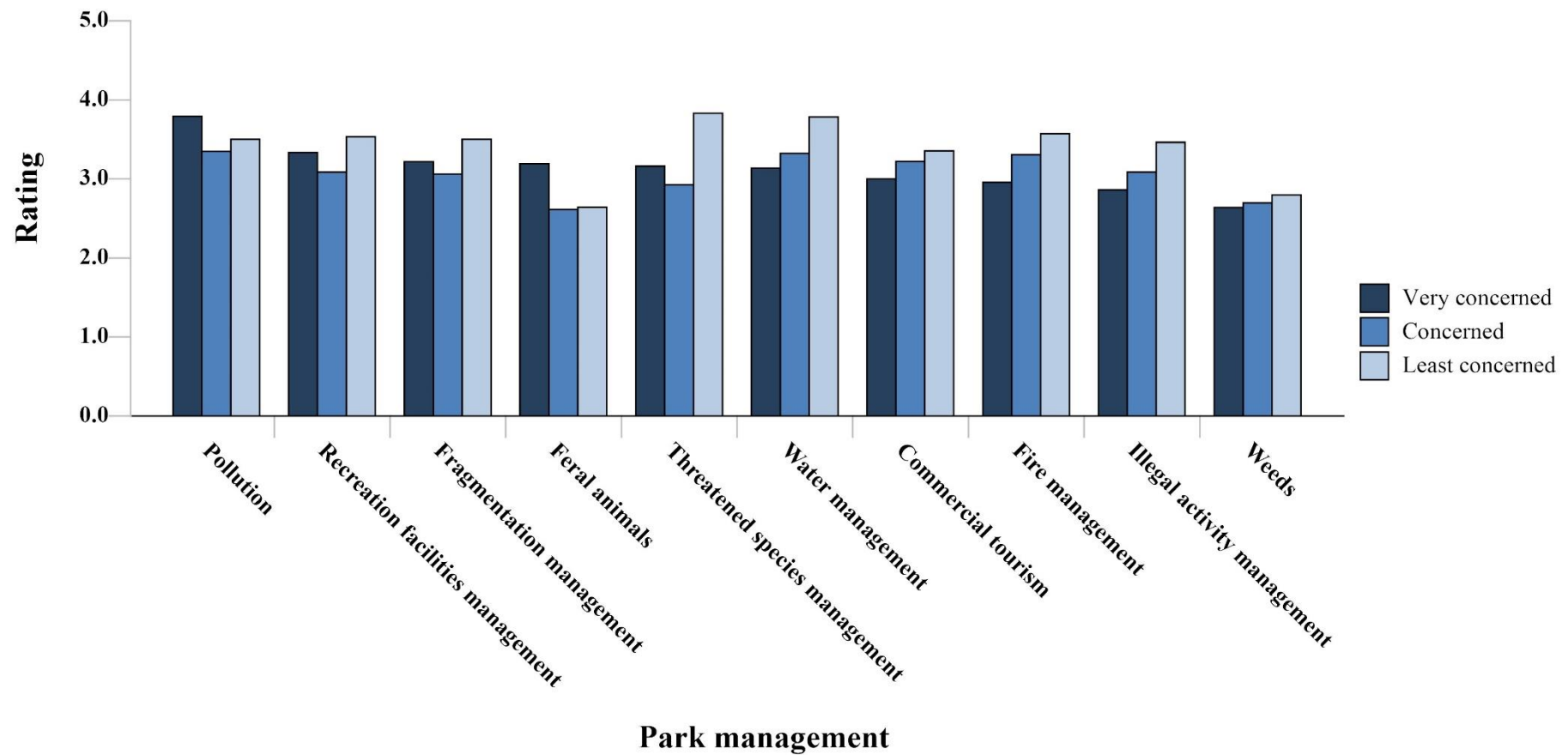


Figure 3-4 Cluster means of how the respondents rated how they perceived current park management is (0 - not managed well at all, 5 - managed very well).

There was negligible difference in how they perceived park management; all three groups rated management between 2.6 and 3.8 (0 - not well managed, 5 - very well managed). The 'least concerned' group generally rated management more highly except for pollution and feral animals (Figure 3-4).

### **3.4 Discussion**

Our investigation shows there are a large number of similarities in community, park neighbours and QPWS perceptions and values. A common concern about park threats between the community, park neighbours and QPWS and how parks are managed creates a solid foundation to begin working cooperatively in addressing park management as current issues evolve and new ones emerge. Studies have shown that a collaborative approach to park management with local communities is important for their long term success (Anthony 2007; DeFries et al. 2007; Andrade & Rhodes 2012); therefore, these similarities in concern about park management and park threats will lend support in cooperative conservation planning in and around the Scenic Rim's protected areas. It may assist in the development and implementation of adaptation measures that fall outside park boundaries but support on-park management, such as establishing corridors and reducing fragmentation.

Having similar perceptions with the community and neighbours about park threats may assist QPWS programs and conservation practices and help minimise obstacles to successful implementation on-park. Programs designed based on this knowledge to manage issues, such as weeds, will have a higher success rate. Our study showed a common perception between neighbours and QPWS about weed threats and impacts. This creates a foundation for establishing support from the community and neighbours (Kapler et al. 2012). Springbrook National Park's weed threats for example, are intensified by neighbouring properties with 'English style' tea gardens (QPWS20), and QPWS will need a close working relationship with neighbours and the local community to reduce outside impacts into the park. Having similar perceptions with community and neighbours will also enhance the capacity of protected area managers to combat climate change impacts, such as changing fire requirements, habitat loss, and boundary issues such as feral animal management.

Our results showed significant differences between some or all three groups on particular issues. Differences can result in less positive outcomes; therefore, there is a need to understand these differences to manage dynamic change. Differences in opinion pose challenges for park management (Roca et al. 2011; Allendorf et al. 2012). This can result in social conflict, social and institutional constraint/change, competing priorities, conflicting people-park relationships, escalating visitation and increasing expectations (Lockwood et al. 2006a; Allendorf et al. 2007; Wyborn 2009; Mills et al. 2010). Building relationships, education and information sharing where there are differences in opinions is valuable in combating these obstacles. Our study on the Scenic Rim revealed QPWS's perception of introduced animals as a threat was significantly different to that of both the community and neighbours. Park managers could consider affording this and similar issues a higher priority, not only to deal effectively with these threats, but also with the aim of building positive relationships with neighbours.

It also showed that the distance one lived from a park also was a factor in perceptions of introduced animals. This is possibly due to higher sightings of feral species in or near protected areas and their perception of them as an 'exotic' species resulting in a negative impact on park values. For example, studies have shown that awareness of feral pigs can increase people's perception of them as a higher threat (Koichi et al. 2012). This could be beneficial in implementing compatible surrounding land use management, a higher concern may result in a more supported cooperative approach.

Differences in park manager and community/neighbours perceptions of park management effectiveness presents other challenges. It is difficult to gather support to increase threatened species management for example, if the general community believe that current management is adequate. The community may value the species less than park managers, are not fully aware of their status and issues, or the protected areas may be providing a false sense of security about threatened species protection. The community and park neighbours may also see threatened species management as responsibility of park managers and are unaware of their ability to have some bearing on species management outcomes. Protected area management outcomes are highly associated with involvement with communities and stakeholders (Leverington et al. 2010). If park managers can gain insight into the

community's beliefs and perceptions, they can design more appropriate programs to support and adapt management as changing impacts become evident.

Our investigation demonstrated that the views of neighbours diverge considerably more from QPWS perceptions than community views. Neighbours affected by protected area management through wildfires, feral species and weed issues may see park management in a more negative light. Other neighbours may have a personal interest in park values; hence the choice to live adjacent to a park and an associated interest in park management. These motives could lead to differences in perceptions and promote hostility between park managers and neighbours. Given that surrounding land management directly influences parks, this diversity in values and perceptions with neighbours needs to be understood by managers seeking collaborative management of current and emerging impacts such as the impact of fire regimes on the state of rainforest ecosystems of the Scenic Rim.

Understanding these differences is important in Queensland, and in park management in general. Park staff indicated that public concerns can often guide management and community priorities and influence park management. In Queensland, park management and direction is provided by the Queensland Government giving support and resources for park management through the *Nature Conservation Act 1992* (Qld), and the World Heritage listed parks through Australian federal legislation, the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth). This ensures the public have some participation in how protected areas are planned and managed. Differences in management perceptions that drive park management decisions may result in undesirable ecological impacts. On Springbrook National Park, pressure from local residents to allow rainforest succession has led to reduced prescribed burning regimes and increased wildfire hazard. This has resulted in rainforest being burnt in the past with devastating impacts on rainforest biodiversity (QPWS11). Predictions in South East Queensland suggest an increasing number and intensity of fires over longer fire seasons, increasing this wildfire potential (Liu et al. 2010; Penman et al. 2011). These sorts of issues could provide devastating results for some ecosystems if not managed cooperatively.

### **3.5 Conclusion**

There are demonstrated links between perceptions and behaviour (Winter & Lockwood 2005; Freuler & Hunziker 2007; White et al. 2008) and an understanding of people's beliefs can help managers to influence their behaviour (Brown et al. 2010.). Awareness of values held by the community and neighbours can give protected area managers an understanding of why people undertake certain activities that may impact upon parks.

A good understanding of the social context in which protected areas are positioned can help guide park managers in how to communicate and work with the local community and neighbours to gain the most effective and productive outcome in adapting management for change. It lessens the risk of undesirable outcomes and will enhance management in a world where park management resources are in short supply.



## **Chapter 4**

### **Applying models to understand likely impacts of climate change on protected areas**



Plate 4 – Antarctic beech *Nothofagus moorei*

**‘A single tree cannot make a forest’ – Nigerian Proverb**

This chapter is an extension of the publication submitted to Australasian Journal of Environmental Management, submitted as Tanner-McAllister, SL, Rhodes, JR & Hockings, M 2016, 'A comparison of climate change impacts on park values for four Queensland World Heritage National Parks in Australia'.

## **4.1 Introduction**

Climate change is one of the most significant issues facing our natural environment (Sommer et al. 2010). Globally, there has been detectable increases in land and ocean surface temperatures, sea temperatures, ocean salinity and sea levels over the last three decades (IPCC 2013; Savage & Vellend 2015). Climate change projections of an increase in average temperatures are likely to exceed 1.5 - 2°C (relative to 1850 to 1900) by the end of this century (IPCC 2013). There are expected changes to the global water cycle, altering precipitation with an increase in intensity and frequency of precipitation events, and an increase in average global ocean temperatures and sea levels (IPCC 2013). These changes in climate are expected to have significant impacts on biodiversity (Sommer et al. 2010) including protected areas (Monzon et al. 2011).

Some protected areas are already experiencing climate change related impacts such as movement in a species' geographical distribution, local extinctions and ecosystem modifications (Hannah et al. 2007; Kitching et al. 2011; Monzon et al. 2011; Eigenbrod et al. 2015). Protected area management activities are generally focused on a static view of values and often managed in isolation from surrounding landscapes (Lemieux et al. 2011b; Monzon et al. 2011). This contradicts many of the recommendations for improving climate change adaptation through managing for change and landscape scale strategies (Hobbs et al. 2006; Fischman et al. 2014). A key question therefore is how should existing protected areas be managed for climate change impacts in the future?

Protected areas generally require management to maintain or improve condition of the values that the park was originally set aside to conserve. In many situations, key park values are affected by some form of threat and require management intervention (Moore & Hockings 2013) to be sustained. However, limited resources, competing public interests, increasing and novel threats, changing political environments and demands from a diversity of stakeholders can impede a manager's ability to manage parks effectively (Leverington et al. 2010; Bode et

al. 2011; Swemmer & Taljaard 2011). The emergence of climate change as a factor likely to affect protected areas, increases uncertainty around determination of appropriate management strategies and actions. Decision analysis and support systems can improve planning for management for park specific climate change impacts by increasing knowledge of potential threats and impacts, exploring and accommodating increasing uncertainty and providing a framework in considering stakeholder contributions (Cain et al. 2000; Addison et al. 2013; Fischman et al. 2014). There is a lack of knowledge of how local scale differences between broadly similar parks within a regional area might vary in terms of impacts and effective responses.

Bayesian Belief Networks (BBN) are an approach that is gaining traction as an effective tool to support decision making, particularly where there are interacting drivers, a lack of data and a high level of uncertainty (Cain et al. 2000). BBNs are effective because they utilise expert knowledge (Kuhnert et al. 2010) where data is lacking and can facilitate the practical application of adaptive management because models are easily updated as more information becomes available (Newton et al. 2007). They can also assist in communication and facilitate stakeholder involvement (Cain et al. 2000; Zorrilla et al. 2010). They provide support for management decision making by providing a visual way of representing uncertainty about the outcomes of management intervention and identifying which management responses are likely to be most effective (Newton et al. 2007).

Twelve BBNs were developed across four of Queensland's Gondwana Rainforest of Australia World Heritage listed protected areas based on three key values that are vulnerable to climate change; stream dwelling frogs, cool temperate forest, and walking tracks. The BBNs were developed to assess likely climate change impacts on these key values and compare the four parks to understand how they might differ from one another in terms of threats and impacts and likely effective management responses.

## 4.2 Methodology

### 4.2.1 Study site and protected area values

The Scenic Rim is a mountain system in South East Queensland, Australia along the Queensland/New South Wales border extending westward from the Gold Coast (Queensland) hinterland. It includes the Gondwana Rainforests of Australia World Heritage protected areas Springbrook, Lamington, Mount Barney and Main Range National Parks (Figure 1-3). Each park has similar values for which they were protected, however they vary in characteristics such as size, shape, surrounding land use and climate (Appendix 1, Table 8-3).

The parks are predominately rainforest and wet sclerophyll forest, with many of their values considered to be under threat from climate change (Australian National University 2009; Tanner-McAllister et al. 2014). The region is expected to experience an average annual decrease in precipitation, increase in storms and extreme weather events, and an increase in average temperature (Dowdy et al. 2015). An increase in fire risk, and rise in orographic cloud level is also anticipated (Australian National University 2009; Dowdy et al. 2015).

This research focuses on a group of species (stream dwelling frogs), an ecosystem (cool temperate forest) and visitor value (walking tracks), all expected to be subjected to climate change impacts. Frogs are particularly susceptible to climate change and are experiencing declines worldwide (Barrett et al. 2014; Penman et al. 2015). Stream dwelling frogs (i.e. *Mixophyes fleayi*, *Philoria loveridgei*, *Litoria pearsoniana*) are sensitive to changes in environmental conditions, and likely to be impacted by reduced rainfall, increased temperatures, changes in fire regimes, and increasing storm events (Hoskin et al. 2013).

The high altitude forests of the Gondwana parks comprise of cool temperate forest and support many endemic species that rely on high moisture habitats from both precipitation and mist from cloud cover (Pounds et al. 1999; Laidlaw et al. 2011b). Cool temperate forest are found across all four parks, typically dominated by Antarctic beech *Nothofagus moorei* on Springbrook, Lamington and Mount Barney National Parks, and Lilly pilly *Acmena smithii* on Main Range (Hunter 2004). These cloud forests and cool temperate forest habitat dependent species are highly vulnerable to climate change and expected to be impacted from loss of moisture and rising orographic cloud cover (Laidlaw et al. 2011b; Oliveira et al. 2014).

The Gondwana parks are heavily used by visitors for nature based recreation, particularly Springbrook and Lamington National Parks due to their close proximity to the Gold Coast, a densely populated city and international tourist destination (Tourism Research Australia 2013; Queensland Government Statistician's Office 2015). Walking tracks are a significant recreational feature of all four parks. The walking tracks have already experienced an increase in climate change impacts from drought and increased storm activity resulting in landslides and other impacts such as erosion and tree falls. Tracks have been frequently closed for significant periods of time because the requirements for track reconstruction exceed the management staff and resources available (pers. comm. QPWS, walking track workshop participant, 2015).

#### **4.2.2 Bayesian Belief Networks**

Bayesian belief and decision networks are graphical and probabilistic models based on Bayesian probability theory, developed to assist decision making under uncertain conditions (Cain et al. 1999). They have several advantages in natural resource and conservation management. They can quantify the relationship between variables (Walshe & Massenbauer 2008; Liedloff & Smith 2010), accommodate uncertainty arising from data sources such as expert knowledge (Ellison 1996; Newton et al. 2006; Liedloff & Smith 2010; Zorrilla et al. 2010), and be used for prediction and diagnostic analysis (Liedloff & Smith 2010). They can be updated as new information becomes available (Marcot et al. 2006; Walshe & Massenbauer 2008). They can incorporate stakeholder views and help structure the participatory process when public participation is required (Bromley et al. 2005; Zorrilla et al. 2010). They can integrate a wide variety of data including case data and expert knowledge and works well with uncertainty and missing data.

They are becoming more widely used in ecological, environmental and conservation management (Cain et al. 1999; Marcot et al. 2006). BBNs have been used for species management (Murray et al. 2009; Penman et al. 2009; McDonald-Madden et al. 2010), adaptive management (McCarthy & Possingham 2007; Howes et al. 2010; McDonald-Madden et al. 2010), natural resource planning (Cain et al. 1999; Bromley et al. 2005; Graham et al. 2008; Walshe & Massenbauer 2008; Galan et al. 2009; McCloskey et al. 2011), and risk management (Marcot et al. 2006; Hough et al. 2010). Likewise they are used for eliciting expert knowledge (Choy et al. 2009; Kuhnert et al. 2010) and decision making when

there is a lack of information or data (Kuhnert et al. 2010). They have also been used for predicting future ecological changes (Marcot et al. 2006; Langmead et al. 2009; Liedloff & Smith 2010; Shenton et al. 2010).

BBNs are particularly useful in incorporating social aspects into natural resource management (Cain et al. 1999; Newton et al. 2006). They have been used as tools to incorporate stakeholder participation by providing a framework to incorporate their opinions and used as a communication tool for explaining complex systems (Bromley et al. 2005; McCann et al. 2006; Newton et al. 2007). BBNs are suitable for assessing climate change adaptation because they can account for uncertainty where datasets are scarce and expert opinion is required, and can explore causal relationships (Richards et al. 2013).

BBNs were the chosen method because the framework is designed for protected area managers in decision making whom generally do not have the skills, time, or resources to obtain scientific evidence for developing effective management options (McCloskey et al. 2011). There is also a lack of scientific evidence for other modelling procedures.

Bayesian belief and decision networks are very practical for assisting management of protected areas under climate change as they fit nicely into an adaptive management framework (Howes et al. 2010). They can be ongoing and be updated with new data as it becomes available as well as used for prediction and diagnostic analysis, increasing accuracy and decision making in an adaptive framework. Once validated, BBNs can also identify where uncertainties lay and identify data gaps to help focus future research (Howes et al. 2010).

#### **4.2.3 Model development**

Conceptual models were developed for each value following guidelines in Marcot et al. (2006). Draft models were created based on the literature and interviews conducted in Chapter 3 and then distributed to experts for comment. Discussions were held over the phone or in person for input by experts to further develop and finalise the conceptual models. The aim of the models was to explain each value in a simple format, the major drivers of the system and how they relate to each other.

Experts for the purposes of development of the BBNs are individuals with specialised knowledge (i.e scientists and/or practitioners) in the distinct components of the BBNs, and experiences in climate change impacts where possible. Experts were chosen based on the extent of knowledge of the value and of the protected areas. Four experts were interviewed for the stream dwelling frog model, ecologists specialising in the species in question, particularly in those parks or of very similar circumstances. A total of eight experts were interviewed for the cool temperate forest models, four rainforest ecologists with specialised knowledge in high altitude rainforests and four fire experts with the QPWS with particular knowledge of the fire management within the Scenic Rim and South East Queensland. Six QPWS rangers from across the region with very good, long term knowledge of the protected areas and walking track management within the region were consulted for the walking track models. Use of experts for parameterising BBNs can range from one to many; for this research multiple experts were employed for estimating a standard error (Kuhnert et al. 2010).

The conceptual models were then converted to BBNs in Netica (Norsys Software Corporation 2010). A BBN was developed for each value for each of the four parks in the study area, i.e. total of 12 models (Appendix 4). Due to a lack of quantitative data, expert elicitation was used to populate the conditional probability tables with the same procedure used for each model. Conditional probabilities were gathered through individual interviews for the stream dwelling frog and cool temperate forest models, and a workshop was conducted for the walking track models. Individual interviews were undertaken A workshop was required for participating park rangers with less scientific background, and to promote discussion about parks that rangers were less familiar with (McBride et al. 2012). The use of expert elicitation reduces the accuracy of these models somewhat than models that might be based on large amounts of ecological information, however it provides the relevant information required to for the decision making framework, within this thesis.

Conditional probabilities for each child node of the BBNs were gathered using Microsoft Excel. Bar graphs representing figures provided a visual representation to assist expert input and reduce errors. For the individual interviews, group averages and standard deviations were calculated from the initial estimates. These were then made available to the experts, who then had the option of adjusting their original estimates (Linstone & Turoff 1975; Martin et al.

2012; McBride et al. 2012). Final averages were used for the conditional probability tables in the BBNs (Martin et al. 2012). The workshop for the walking track models gathered the conditional probabilities in a similar manner. Each ranger populated individual conditional probabilities into Microsoft Excel. Averages and standard deviations were then presented to them in the second half of the workshop upon which they made adjustments to their original figures they felt were warranted (Linstone & Turoff 1975; Martin et al. 2012; McBride et al. 2012). Final figures were then averaged and used for the BBN conditional probability tables. (Martin et al. 2012; McBride et al. 2012).

Once the BBNs were completed, each model was tested by trying different combinations by altering the status of various nodes and observing their response to assess for any unrealistic behaviours. For example, the literature maintained that moisture and orographic cloud cover was a large influence on the presence of cool temperate forest, so there was the expectation that changes to the cloud immersion node would influence the cool temperate forest health node. Secondly, a sensitivity analysis was run using calculations of variance reduction and entropy reduction to verify the model structure and parameterisation (Marcot et al. 2006). Again, based on literature and interviews with the experts and park managers, expectation of which nodes should be most sensitive were established to assess any unusual behaviours.

### **4.3 Analysis of the models**

A sensitivity analysis calculating variance of belief was undertaken for each of the 12 models on the final output nodes. Each sensitivity analysis was carried out under a 'best case' and 'worst case' scenario to assess the sensitivity of the final output nodes to different elements of the models. 'Best' and 'worst case' scenarios were established by setting all nodes to the optimal or worst condition.

The models were then used to process a number of scenarios to predict possible outcomes under different management situations to give an indication of how the values on each park may be impacted and may respond to climate change. Models were first run as a 'best case' scenario (i.e. current climate and good management) to assess how final output nodes respond to a range of scenarios. Different nodes were altered to reflect variations in management to investigate changes in final node probabilities. Different combinations of



management nodes were also performed under ‘moderate’ and ‘substantial’ climate change scenarios.

#### 4.4 Results

For the analysis, groups of nodes (climate and management variables) were used represent ‘current’, ‘moderate’ and ‘substantial’ climate change; ‘good’ and ‘poor management’; and ‘best’ and ‘worst case’ scenarios (Table 4-1). For example, climate variables (blue nodes: Figure 4-1, Figure 4-2 and Figure 4-3) were grouped according to current, moderate and substantial, and park management variables (green nodes: Figure 4-1, Figure 4-2 and Figure 4-3) were set to good or poor. A ‘best case’ scenario consisted of ‘current’ climate variables and ‘good management’, and ‘worst case’ scenario set to ‘substantial’ climate change and ‘poor management’.

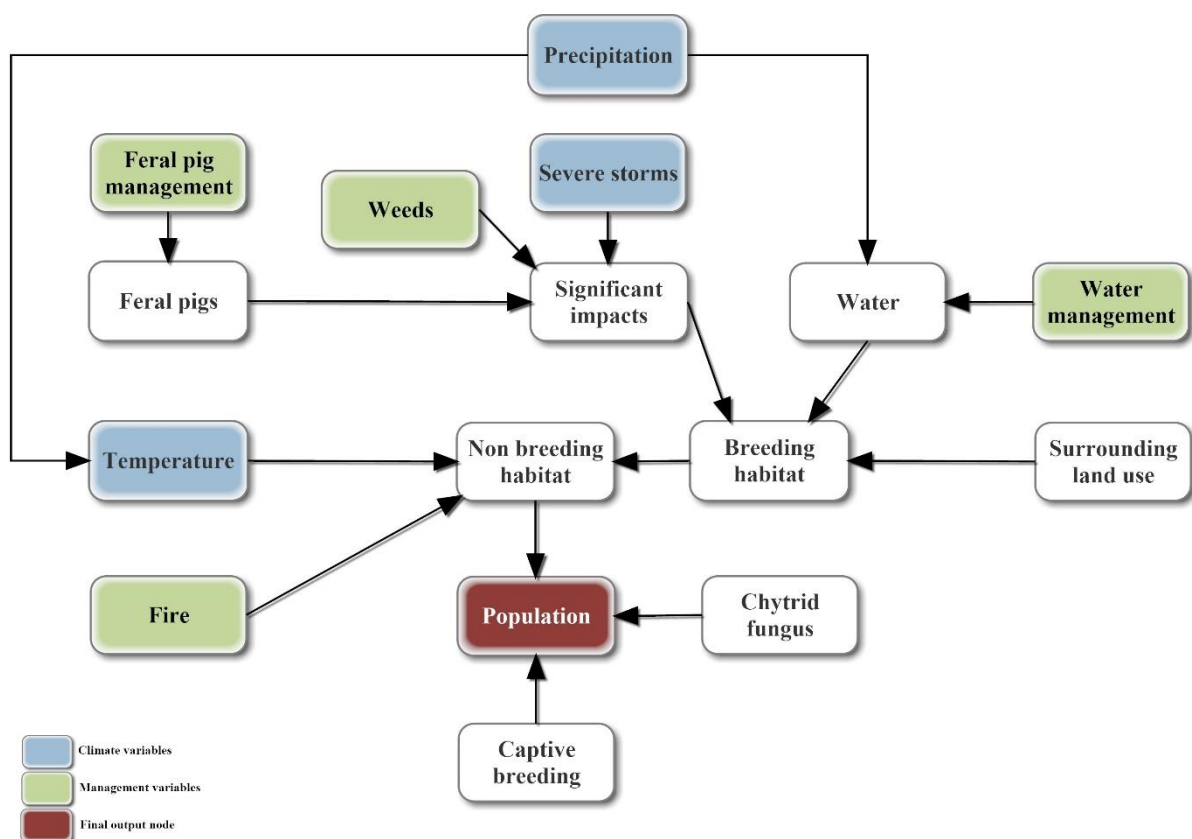


Figure 4-1 Conceptual model for stream dwelling frogs.

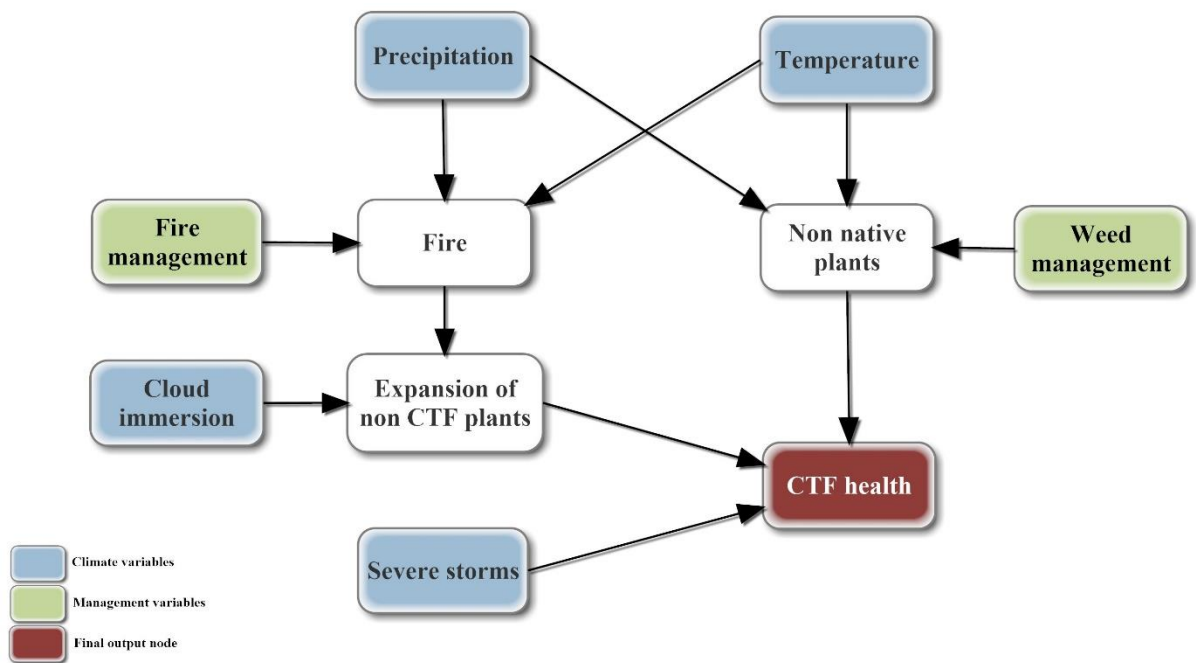


Figure 4-2 Conceptual model for cool temperate forests (CTF).

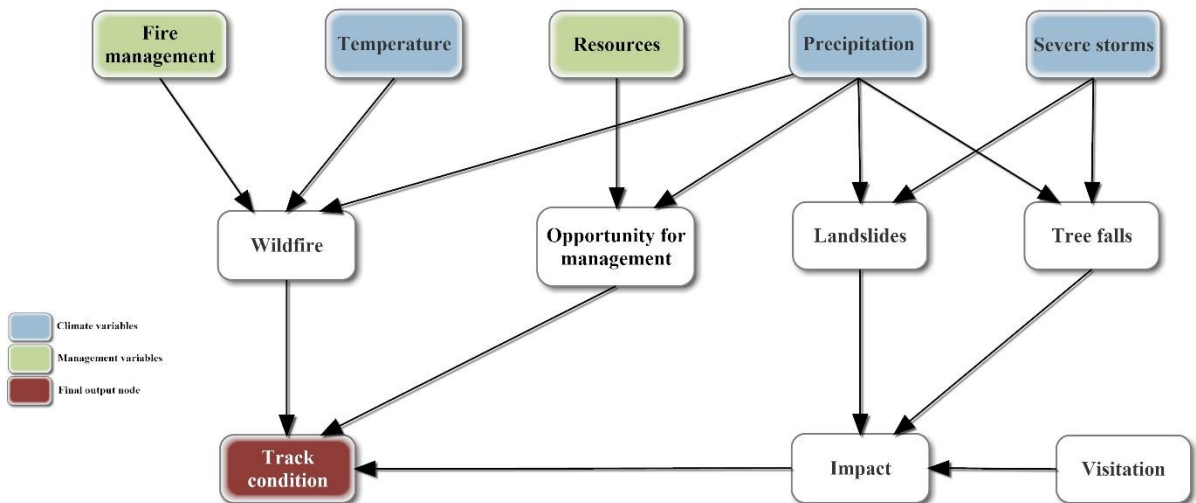


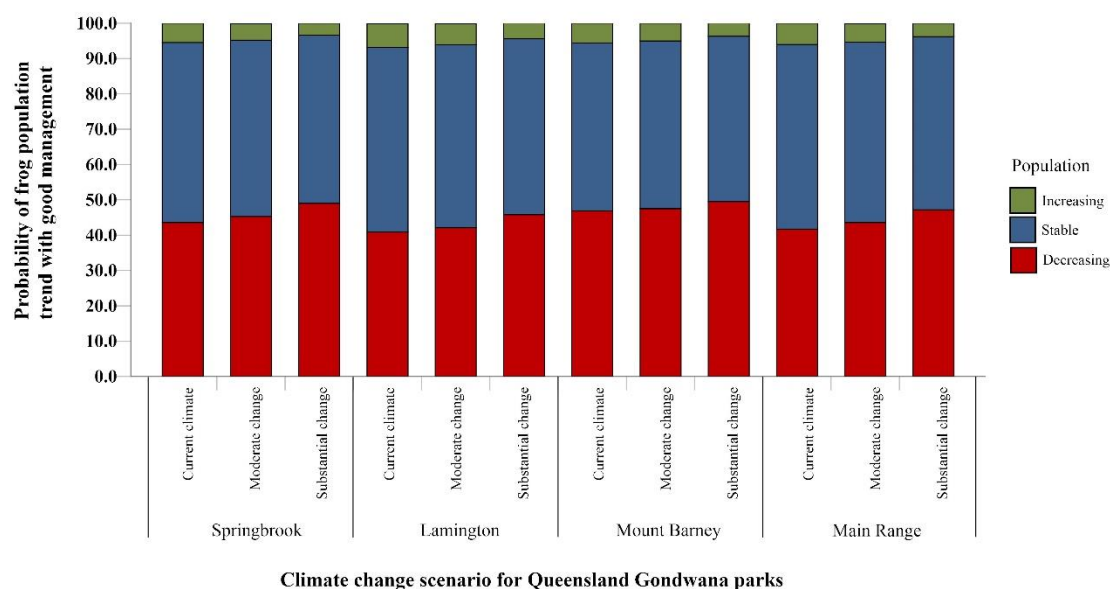
Figure 4-3 Conceptual model for walking tracks.

**Table 4-1 Groupings of conceptual model and BBN nodes used for analysis (specific details in Appendix 4).**

|                             |                            | <b>Stream dwelling frogs</b>   | <b>Cool temperate forest</b>   | <b>Walking tracks</b>  |
|-----------------------------|----------------------------|--|--|--|
| <b>CLIMATE VARIABLES</b>    | Current climate            | Current precipitation; current severe storms; current temperature  | Current precipitation; current severe storms; current temperature; current cloud immersion   | Current precipitation; current severe storms; current temperature                            |
|                             | Moderate climate change    | Low decrease in precipitation; low increase in severe storms; low increase in temperature                  | Low decrease in precipitation; low increase in severe storms; low increase in temperature; moderately higher cloud immersion       | Low decrease in precipitation; low increase in severe storms; low increase in temperature    |
|                             | Substantial climate change | High decrease in precipitation; high increase in severe storms; high increase in temperature               | High decrease in precipitation; high increase in severe storms; high increase in temperature; substantially higher cloud immersion | High decrease in precipitation; high increase in severe storms; high increase in temperature |
| <b>MANAGEMENT VARIABLES</b> | Good management            | Water management - appropriate; feral pig management - yes; fire - planned; weeds - low                    | Fire management – good; weed management – good   | Fire management - appropriate; resources - appropriate                                       |
|                             | Poor management            | Water management - not appropriate; feral pig management - no; fire - wildfire; weeds - high               | Fire management – poor; weed management – poor   | Fire management - not appropriate; resources - not appropriate                               |
| <b>ANALYSIS SCENARIOS</b>   | Best case scenario         | current climate; good management; current surrounding land use; chytrid - present; no captive breeding     | current climate; good management   | current climate; good management; suitable terrain; low visitation                           |
|                             | Worst case scenario        | high climate change; poor management; current surrounding land use; chytrid - present; no captive breeding | substantial climate change; poor management  | high climate change; poor management; not suitable terrain; high visitation                  |

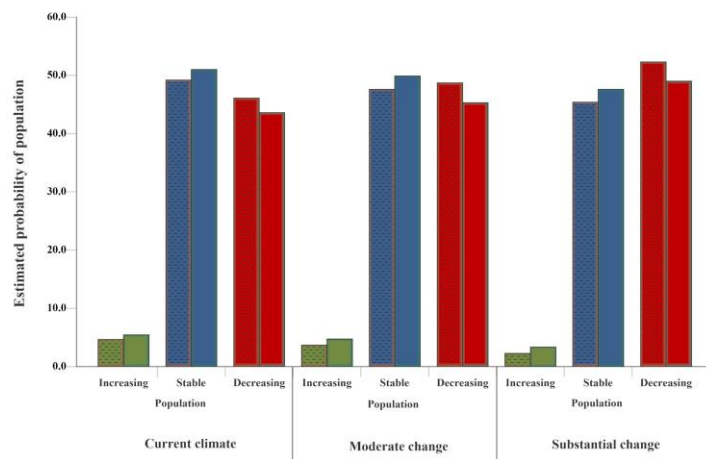
#### 4.4.1 Stream dwelling frogs

All parks showed a lower probability of an increasing population and higher probability of a decreasing population under increasing climate change (increase in temperature, increase in severe storms, decrease in precipitation) with ‘good management’ (Figure 4-4).

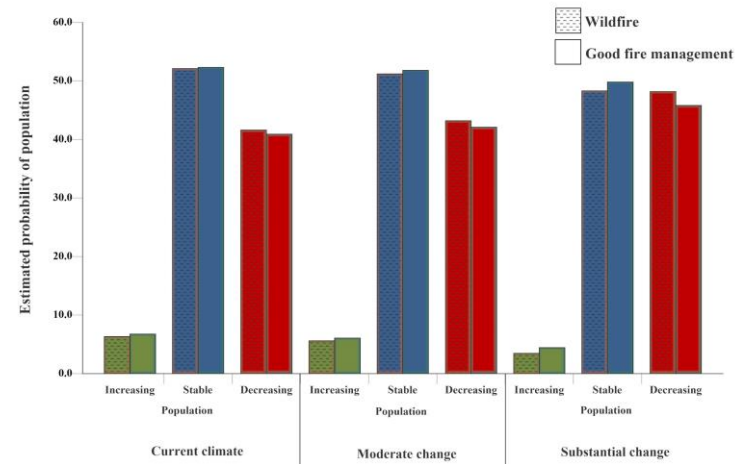


**Figure 4-4** The probability of increasing, stable and decreasing stream dwelling frog population changes under ‘current’, ‘moderate’ and ‘substantial’ climate change scenarios under ‘good management’.

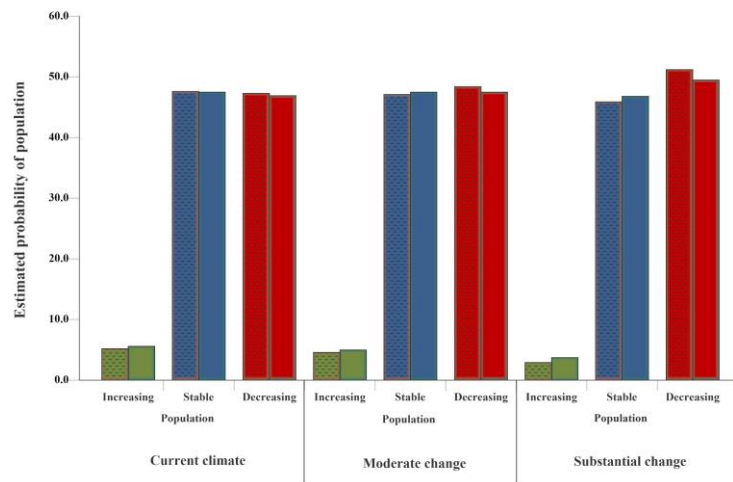
Reducing feral pig or weed management, or implementing inappropriate water management made no major difference to the ‘good management’ scenario. However, increasing the presence of wildfire had a negative effect on the stable and decreasing population under climate change. Springbrook, Mount Barney and Main Range had a much higher probability of a decreasing population under a ‘substantial’ climate change scenario with the introduction of wildfire. Springbrook and Main Range also showed a slightly higher probability of a decreasing population size under a ‘moderate’ climate change scenario. Under a ‘substantial’ climate change scenario, Main Range, Mount Barney and Springbrook all resulted in over a 50% probability that there would be a population decrease. The change in probabilities of negative effects on frog populations with the introduction of wildfire increased as climate change increased (Figure 4-5).



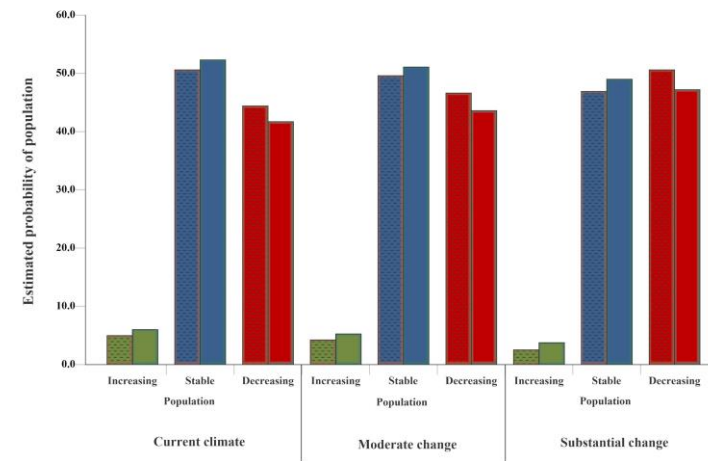
Climate change scenario for Springbrook National Park



Climate change scenario for Lamington National Park



Climate change scenario for Mount Barney National Park



Climate change scenario for Main Range National Park

Figure 4-5 Graph showing the percentage change in probabilities of increasing, stable and decreasing populations with the introduction of wildfire.

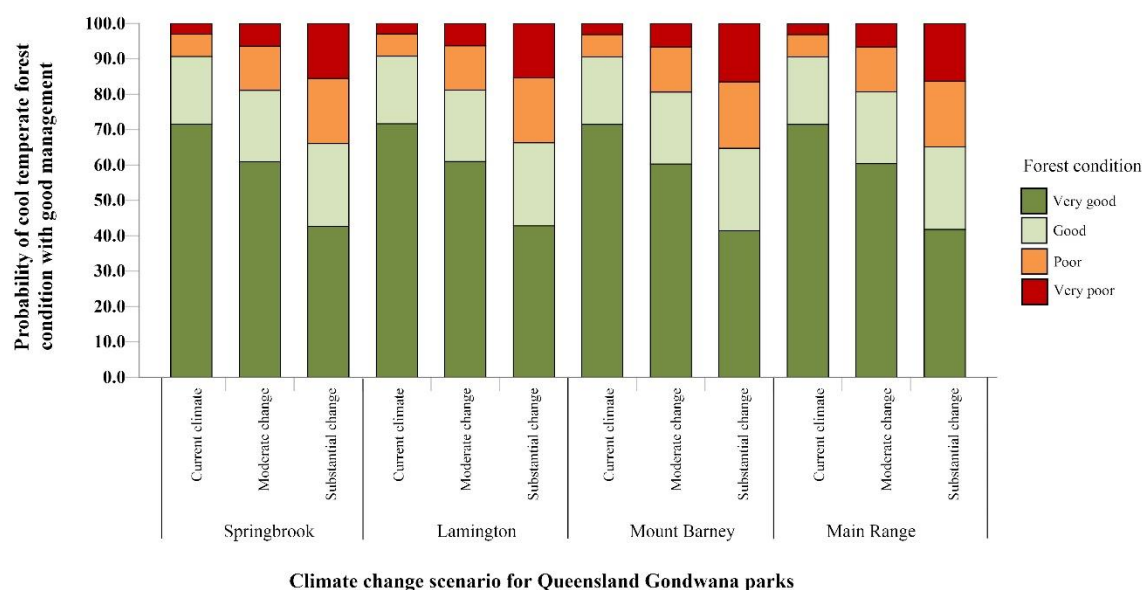
These findings are supported by the sensitivity analysis (Table 4-2) with population health being most sensitive to the non-breeding (drier woodland ecosystems) habitat which is highly influenced by fire.

**Table 4-2 Sensitivity analysis for the final output node ‘population’ for stream dwelling frogs under a ‘worst case’ scenario, variance of beliefs ranked highest to lowest sensitivity.**

|                      | Lamington | Springbrook | Mount Barney | Main Range |
|----------------------|-----------|-------------|--------------|------------|
| Non-breeding habitat | 0.0058587 | 0.0068747   | 0.0036479    | 0.005789   |
| Breeding habitat     | 0.0002010 | 0.0001645   | 0.0000568    | 0.0001853  |
| Water                | 0.0000713 | 0.0000649   | 0.0000200    | 0.0000669  |
| Significant threats  | 0.0000096 | 0.0000069   | 0.0000023    | 0.0000076  |
| Surrounding land use | 0.0000006 | 0.0000035   | 0.0000001    | 0.0000002  |
| Feral pigs           | 0.0000002 | 0.0000002   | 0.0000001    | 0.0000000  |
| Severe storms        | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |
| Chytrid fungus       | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |
| Captive breeding     | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |
| Temperature          | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |
| Fire                 | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |
| Water management     | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |
| Precipitation        | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |
| Weeds                | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |
| Feral pig management | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |

#### 4.4.2 Cool temperate forest

The models for all four parks showed a decrease in the probability of very good forest health under increased climate change. All parks also showed an increase in the probability of poor and very poor forest health as climate change increases (Figure 4-6). Introducing ‘good management’ produced no significant improvement under increased climate change. The sensitivity analysis (Table 4-3) supports these views with the forest health being most sensitive to expansion of non-cool temperate forest which is primarily driven by loss of cloud cover and precipitation and increase temperatures (Foster 2001; Laidlaw et al. 2011b).



**Figure 4-6 The probability of very good, good, poor and very poor cool temperate forest condition under ‘current’, ‘moderate’ and ‘substantial’ climate change’ scenarios. Comparison of Lamington, Springbrook, Mount Barney and Main Range National Parks under ‘good management’.**

**Table 4-3 Sensitivity analysis for the final output node ‘cool temperate forest (CTF) health’ for cool temperate forest under a ‘worst’ case scenario, variance of beliefs ranked highest to lowest sensitivity.**

|                      | Lamington | Springbrook | Mount Barney | Main Range |
|----------------------|-----------|-------------|--------------|------------|
| Expansion of non CTF | 0.0037593 | 0.0034322   | 0.0031337    | 0.003322   |
| Non native plants    | 0.0012799 | 0.0012847   | 0.0016626    | 0.0013523  |
| Fire                 | 0.0000059 | 0.0000124   | 0.0000283    | 0.0000232  |
| Weed mgt             | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |
| Severe storms        | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |
| Cloud immersion      | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |
| Precipitation        | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |
| Temperature          | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |
| Fire mgt             | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |

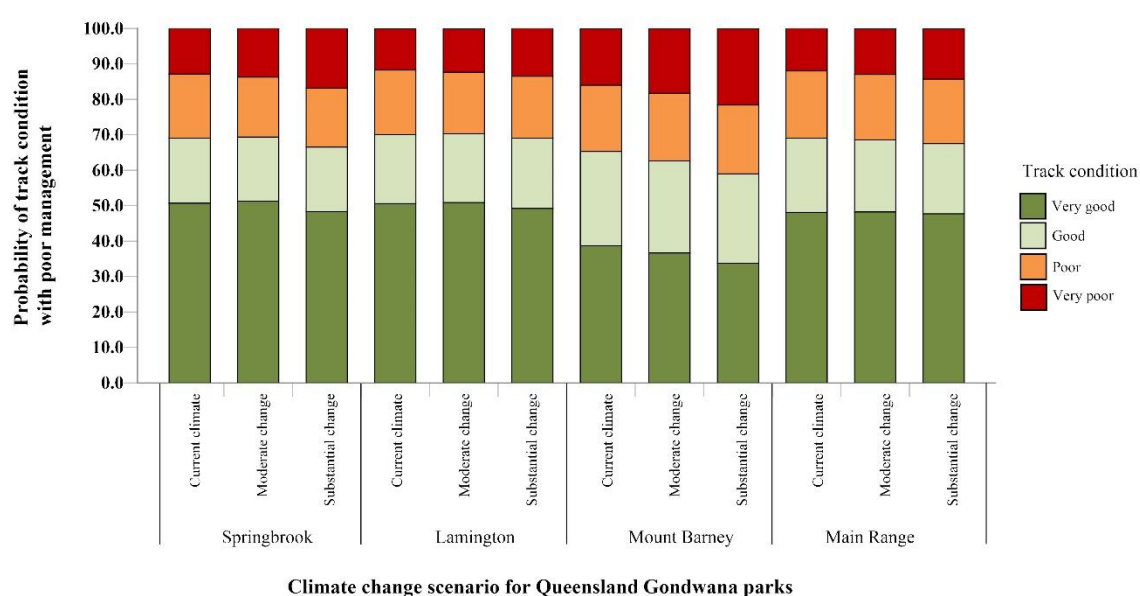
Park management (fire and weed management) had very little influence to the probabilities of maintaining a healthy cool temperate forest when impacted by climate change. Slight improvements were seen with enhanced weed management on Lamington and Springbrook National Parks under both ‘moderate’ and ‘substantial’ climate change, and on Mount Barney

and Main Range National Parks under ‘substantial’ climate change. After expansion of non-cool temperate forest, forest health was most sensitive to non-native plants (Table 4-3) which is in accordance with the model outputs of slight improvements with better weed management.

With an increase in storms, all parks showed a considerable decrease in the probability of very good health under all climate change scenarios. All parks showed a minor increase in the probability of very poor health under ‘current’ and ‘moderate’ climate change, and a more considerable increase under ‘substantial’ climate change with an increase in storms.

#### 4.4.3 Walking tracks

The track condition was assessed under a variety of conditions. All parks showed very subtle changes in the probabilities of the condition of the tracks under climate change with a general decrease in desirable track condition (Figure 4-7). This was dependant on the type of terrain, park management and visitation.



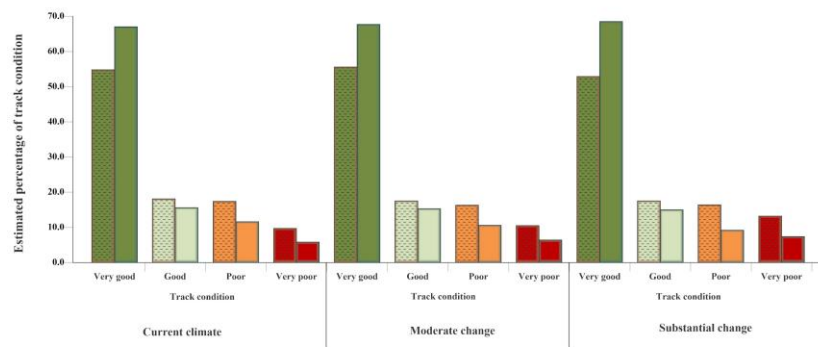
**Figure 4-7** Bar graph showing the probability of track condition on each protected area with ‘poor management’ under ‘current’ climate, ‘moderate’ climate change and ‘substantial’ climate change.



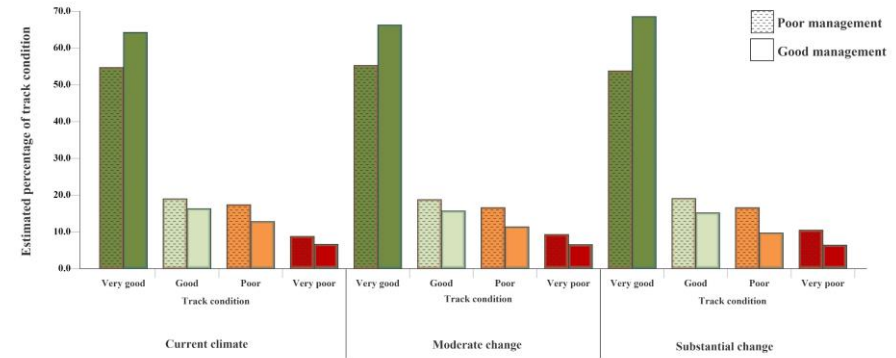
There is a positive change in track condition when ‘good management’ is introduced. The positive change was greater as climate change increased. Figure 4-8 shows the change in walking track condition probability from ‘poor management’ to ‘good management’. All changes represented an improvement in desirable track condition (i.e. an increase in very good or good condition or a decrease in very poor or poor condition), except for the change in good condition on Springbrook, Lamington and Main Range National Parks. These however, were outweighed by the increase in desirable conditions. This was reflected in the sensitivity analysis (Table 4-4) with the track condition node being most sensitive to opportunity for management which is largely influenced by resources.

**Table 4-4 Sensitivity analysis for the final output node ‘track condition’ for walking tracks under a ‘worst’ case scenario, variance of beliefs ranked highest to lowest sensitivity.**

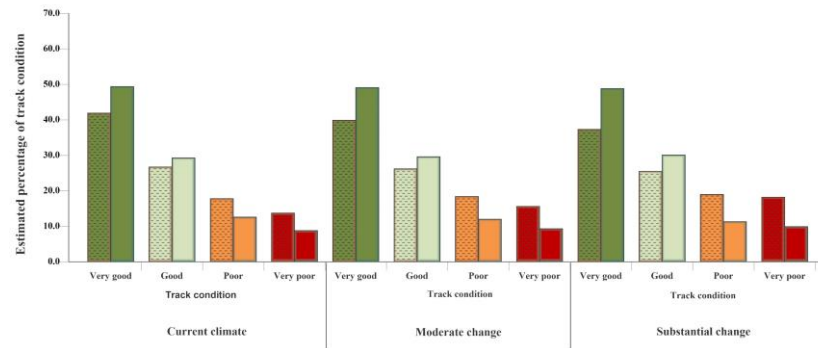
|                            | Lamington | Springbrook | Mount Barney | Main Range |
|----------------------------|-----------|-------------|--------------|------------|
| Opportunity for management | 0.0227071 | 0.0233972   | 0.0121099    | 0.0268079  |
| Impact                     | 0.0032940 | 0.0033857   | 0.0015773    | 0.0029351  |
| Landslips                  | 0.0003437 | 0.0003212   | 0.0001696    | 0.0002969  |
| Wildfire                   | 0.0000466 | 0.0010933   | 0.0005684    | 0.0009588  |
| Tree falls                 | 0.0000790 | 0.0000598   | 0.0000372    | 0.0000631  |
| Visitation                 | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |
| Terrain                    | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |
| Severe storms              | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |
| Resources                  | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |
| Precipitation              | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |
| Fire management            | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |
| Temperature                | 0.0000000 | 0.0000000   | 0.0000000    | 0.0000000  |



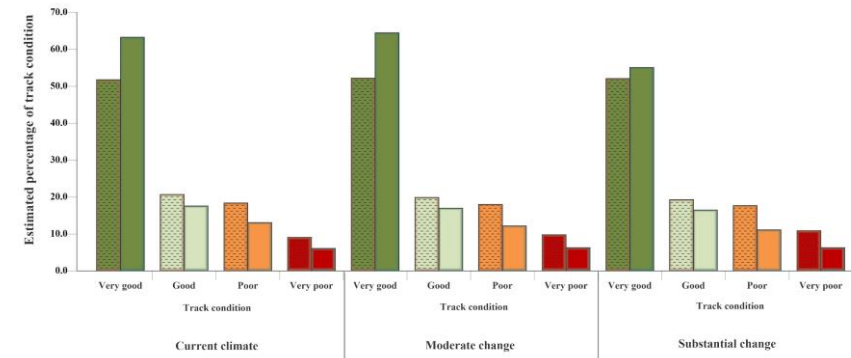
Climate change scenario for Springbrook National Park



Climate change scenario for Lamington National Park



Climate change scenario for Mount Barney National Park



Climate change scenario for Main Range National Park

Figure 4-8 Bar graphs representing probabilities of very good, good, poor and very poor track condition from 'poor management' with the introduction of 'good management'

## 4.5 Discussion

Our results indicate that protected areas within a local region may respond differently to climate change and require different strategies for effective management. In order for park managers to understand how and why particular attributes or values (including species) may be affected differently by climate changes, they must investigate how parks differ in physical attributes, park values, external influences and climatic variables. Springbrook, Lamington, Mount Barney and Main Range National Parks have many common values for which they were designated and are located within the same region. The cool temperate forest models for all parks showed very similar results in terms of both impacts and effectiveness of management strategies under increased climate change. Stream dwelling frog models on the other hand, demonstrated different population sensitivities to various drivers. Stream dwelling frog populations in Lamington were less sensitive to wildfire. This is likely to be due to the park's larger size and smaller boundary/area ratio than Springbrook, and occurrence of moister ecosystems than in Main Range and Mount Barney that would buffer frog populations from the impact of fire.

Springbrook which is a smaller, fragmented park compared to the three other parks in this study exhibited high sensitivity to surrounding land use in the stream dwelling frog model. This supports the argument that larger parks with lower boundary/area ratios are more resilient to external impacts and that smaller parks have less capacity to buffer external influences (Maiorano et al. 2008).

Topography can play an important role in resilience to climate change impacts. The region has provided refuge sites for species and ecosystem protection under past climate change (Shoo et al. 2014). Lamington protects the largest area of cool temperate forest out of the four parks and the plateau topography of Lamington may provide small refuge sites in cool, moist valleys for the cool temperate forest ecosystem. Likewise, Mount Barney appears to be more resilient for the stream dwelling frogs. This park has the largest altitudinal range of the stream dwelling frog habitat in the region and resides higher up in the catchment with virtually no external negative impacts on their habitat.

Topography and catchment location can also affect an area's resilience to external impacts (DeFries et al. 2007). Springbrook showed a high sensitivity to the stream dwelling frog's wet, breeding habitat and water. The park is surrounded by higher density residential and farming land uses than the other parks and is positioned lower in the catchment and suffers from downstream impacts of external land use. Lamington has some adjoining land uses above the stream dwelling frog habitats, however much less than Springbrook. It has been suggested Lamington may experience effects from water extraction which may well be a factor in the models results of this park's high sensitivity to water under a 'worst case' scenario (stream dwelling frog model participant pers. comm., 2015). Increasing density and depth of pools as well as connectivity has been shown to likely reduce tadpole mortality from drying effects under climate change (Scheele et al. 2012), therefore additional removal of water under drier conditions may increase climate change impacts on frogs.

#### **4.6 Implications for park management**

There will be some climate change impacts that are not easily managed and will prevent park managers from meeting their goals (West et al. 2009). Direct impacts, in many cases will not be easily managed. For instance, an increase in temperature and decrease in precipitation and/or moisture that have direct impacts on stream dwelling frogs and cool temperate forest are relatively out of a park manager's control within a given location. Frogs are particularly susceptible to climate change most likely causing some population declines (Blaustein et al. 2001; Keith et al. 2014; Turriago et al. 2015) and temperature in particular has been shown to be a significant trigger of climate change impacts to many frogs (Bellakhal et al. 2014; Gao et al. 2015). Many direct impacts like increased temperature are difficult to manage for (Niehaus et al. 2011).

Direct effects from temperature increases and rainfall decreases will also impact on the high altitude rainforest communities that depend on cooler, moist climates. Loss of cloud cover and moisture is deemed to be one of the major impacts of climate change on mist forests across the globe (Krishnaswamy et al. 2014). It is an important factor for cool temperate forest health and a decrease in cloud cover may push this ecosystem out of its ecological niche (Still et al. 1999; Oliveira et al. 2014). In this study area, a reduction in orographic cloud cover is highly likely to result in an expansion of drier rainforests and woodland ecosystems and a reduction or loss of moist, cool rainforest ecosystems. Cool temperate

rainforests are probably the most susceptible of the park's ecosystems to direct impacts of climate change. The models in this study showed that possible management responses made very little difference to maintaining a healthy cool temperate forest as cloud cover and precipitation reduced on all four parks.

These issues have implications for protected area management, particularly where park values are highly significant and loss of species or ecosystems may result in irreversible outcomes such as extinction. Decision making will need to include options such as managing for change and prioritisation (Bottrill et al. 2008; Wilson et al. 2009; Iwamura et al. 2010). For example, Springbrook was less sensitive to impacts on cool temperate forests, however the park protects only a small portion of cool temperate forest (3 ha). The park also has the lowest mountain at 1000 m and likely to be the first of the four parks witness the loss of orographic cloud cover. The choice of park managers may well have to be managing for change and accepting the loss of that value on the park.

There are some direct impacts however that are more manageable. Extreme weather events such as severe storms can directly impact species and ecosystems through damage to forest structures. All models exhibited these direct impacts as a result of increased storms. Severe storms can cause significant damage as seen in 2013 with Cyclone Oswald where large tracks of forest were destroyed (rainforest ecologist model participant pers. comm., 2015). For rainforest already stressed from climate change, storm damage can be a compounding factor reducing regeneration and opening up areas for introduction of weeds (Murphy et al. 2008). All four parks showed a decrease in the probability of very good cool temperate forest health with the increase in storms. In spite of this, park managers can deal with storm damage such as carrying out revegetation or reducing stressors like invasive species.

Storms and associated consequences such as tree falls and landslips also pose a direct threat to visitor infrastructure such as walking track systems. Impacts to the tracks have already been observed on all four parks, particularly Springbrook and Lamington. Lamington has over 150 kilometres of graded walking tracks (Queensland Government 2011). Most of these tracks are in areas of the park that are difficult to access and can be challenging to manage. Lamington's track condition showed it was the most sensitive park to landslips and tree falls under a 'best' and 'worst case' scenario. The BBNs indicated that resources play an

important role in maintaining walking tracks in good or very good condition and all four parks displayed a positive effect with the introduction of appropriate resources.

Many of the indirect impacts may be more within a park manager's control. As the Scenic Rim becomes warmer and drier, fire risk will increase. Fire has shown to be one of the most sensitive factors for the non-breeding areas of stream dwelling frogs and indirect impacts of altered fire regimes and reduction of habitat from climate change are of particular concern (Penman et al. 2015). Fire management will increasingly play an important role in dealing with those habitats and reducing the risk of wildfire.

As moister ecosystems transform to drier types, fire management will become even more significant. Springbrook, Mount Barney and Main Range appeared more affected by fire than Lamington for all three key values and managing fire appears more imperative on Main Range and Mount Barney. These parks have more open woodlands and a drier climate making them more susceptible to wildfire. However, both parks are surrounded by land use comprising largely of grazing. Opinions differ whether this may act as a benefit or a risk. Graziers tend to burn more frequently to maintain grassland systems, which in turn may reduce fuel loads and the risk of wildfires. However, an increase in fire in the region also increases the chances of escaping wildfires. Surrounding grazing land use though, may make it easier for park managers to focus more on ecological style planned burning.

Springbrook on the other hand is surrounded largely by residential land use. Protection of life and property are a very high priority in the Queensland Government's fire policy (Queensland Parks and Wildlife Service 2013) and parks with close neighbouring residential areas may see ecological burning take a 'back seat' (Tanner-McAllister et al. 2014). Some frog species that require fire adapted ecosystems for habitat are particularly sensitive to climate change and its interaction with fire (Penman et al. 2015). The results indicated that the stream dwelling frogs on Springbrook were very sensitive to the changes in their dry, non-breeding habitat. It is likely that the risk of wildfire will increase with climate change due to the parks smaller size and reduced buffering. Springbrook's track condition also demonstrated the highest sensitivity to wildfire. The patchiness and fragmented nature of the park increases this risk to Springbrook's substantial infrastructure of bridges and lookouts.

Invasive species is the other significant climate change related impact. With changing climate variables and increased disturbances from storms, weeds and introduced pathogens are likely to bring additional problems (Hellmann et al. 2008). This matter is becoming a serious concern and is one of the least predictable impacts being explored (Campbell 2008; Bradley et al. 2010; Gallagher et al. 2010; Taylor & Kumar 2013). All four parks showed some slight improvements for cool temperate forest health under climate change as a result of improved weed management. To some extent, invasive species can be controlled and managed to increase resilience and reduce negative impacts on protected areas. However to accomplish this, weed management will require agency support and an injection of resources.

#### **4.7 Conclusion**

BBNs can prove useful in assisting protected area managers to understand how their protected area may be impacted by climate change. They provide a basis for discussions on options for response and directions for park management into the future. For the purposes of protected area management decision making, they are not designed to give definitive answers but to provide support to begin dialogue and reduce as well as accommodate increasing reduce uncertainty for managers in how best to proceed with adapting management for climate change.

Limited funding and competing interests compels park management to become more efficient, but still remain effective in their management. The cost of implementing some management strategies to combat climate change may make them unpractical.

Historically, park management agencies have focused on individual park management with an intention to maintain existing park values. With climate change, decision making will need to begin making decisions such as accepting loss or change to some park values. This will be the reality that managers must face as many impacts may be outside their ability to manage.

# **Chapter 5**

## **Climate change management framework for decision making on protected areas**



**Plate 5 - Black snake ridge, Lamington National Park**

**‘If we do not change direction, we are likely to end up  
where we are headed’ — Chinese proverb**



This chapter is an extension of a journal article to be submitted for publication.

## **5.1 Introduction**

Climate change is inevitable and we can deal with the impacts either through mitigation or adaptation (Fussel 2007). The United Nations Framework Convention on Climate Change (UNFCCC) identifies both of these as responses to climate change. Mitigation aims to reduce the rate and magnitude of global warming by reducing atmospheric greenhouse gases (Jones & Preston 2006; Klein et al. 2007). Adaptation increases the system's ability to cope with changes by adjusting to climate change impacts (Jones & Preston 2006; Klein et al. 2007). However, it is not a question of whether to mitigate climate change or to adapt to it, in order to reduce expected impacts, both are now essential (Burton et al. 2002; Klein et al. 2007) and are considered complementary rather than mutually exclusive alternatives (Fussel 2007).

Protected area management is facing an assortment of impacts from climate change such as ecosystem changes and deterioration, species distribution changes and extinctions, invasion of non-native species, and changes in community and ecosystem processes (Rosenzweig et al. 2007; Gonzalez 2010). This will have a bearing on protected area management which therefore will have to incorporate adaptation into park strategies in order to cope with these impacts.

Smit et al. (2000) analysed several meanings of adaptation and found several things in common, 'they all refer to adjustments in a system in response to (or in light of) climatic stimuli', they imply changing to 'better suit' new conditions. There needs to be a clear understanding that adapting is not just coping with climatic changes, but actually undertaking actions to adjust to it. Eriksen and Kelly (2007) distinguish between adaptation and coping in that adaptation is an adjustment in practices to the actual threat of long term climate change, whereas coping are actions in response to present climatic stress. Nonetheless, adaptation can be reactive where measures are put in place afterwards in response to climate change or anticipatory where measures are put in place in advance of climate change (Fankhauser et al. 1999). In order to deal with climate change effectively, anticipatory adaptation with long term objectives is essential. It is generally less expensive than relying on just reactive adaptation (de Bruin et al. 2009) and should include long-term planning and research (Fankhauser et al. 1999).

The question is, how do protected area managers undertake anticipatory adaptation to modify protected area management to suit climate change. This chapter carried out an analysis of the management options of the framework presented in Chapter 2 (Figure 2-1) through a workshop with QPWS planners and managers to assess probable management strategies for Springbrook, Lamington, Mount Barney and Main Range National Parks. The aim was to assist protected area managers with an objective decision making process for these parks in response to climate change.

### **5.1.1 Methodology**

A scenario planning approach was used to assist decision makers in approaching protected area management under climate change. Traditional methods of decision making for protected area management are based upon well-defined goals for efficient and effective management under relatively stable environmental conditions (Peterson et al. 2003). Management under climate change however presents novel situations in uncertain conditions that will present unexpected outcomes. Scenario planning provides a systematic approach for assessing complex situations under probable future conditions, taking into account uncertainty and unexpected outcomes, assessing potential impacts of alternative management options (Peterson et al. 2003; Imong et al. 2016; Mitchell et al. 2016), and potentially identify maladaptation (Butler et al. 2016).

The assessment was conducted by means of a workshop with managers and protected area planners with the QPWS. The workshop carried out a decision making activity to assist managing Queensland's Gondwana parks under climate change. The workshop involved five QPWS officers involved in planning and managing the Queensland protected area estate.

A workshop was the chosen method to obtain this data for several reasons. One, as part of a procedure developed for park managers, it provides an efficient means to gather data where time and resources are limited in management planning. Secondly, it provided a means to promote discussion amongst planners and park managers to exchange information in order to increase accuracy in the data generated. Lastly, it provided an opportunity to confirm or dispute information gathered from interviews conducted in Chapter 3 and discuss issues that arose to further manage those protected areas more effectively.

A presentation was given at the beginning of the workshop outlining the decision making framework, the climate projections for the region, and the results of the Bayesian Belief Networks (i.e. Chapter 4). The participants were then presented with a questionnaire (Appendix 5) for each of the values (i.e. stream dwelling frogs, cool temperate forest, walking tracks) for Springbrook National Park. Each of the questionnaires included information and data on how the value might be impacted upon by climate change across all four parks, how important that value is for that particular park, and the vulnerability of that value (Appendix 5). As a group, each of the participants worked through assessing the three values on Springbrook supported by discussion within the group.

The values were assessed against each of the six strategies (i.e. do nothing, change management and build resilience, modify the existing system, hard engineering, soft/ecological engineering, and change management/use and build resistance). The questionnaire (Appendix 5) included examples of actions for each of the six strategies for each of the values (e.g. water sprayers, irrigation, shelters for hard engineering actions for stream dwelling frogs). These six strategies and possible actions were discussed within the group to ensure each participant fully understood their definitions. The probability of success for each of the strategies was defined as how much a strategy meets the objective of accepting or preventing change. For the stream dwelling frogs, this included a stable or increasing population, for the cool temperate forest this was maintaining the ecosystem in good or very good health, and the walking tracks was maintaining them in good or very good condition according to criteria set out for the BBNs workshop in Chapter 4 (Appendix 4). The probability of success of each strategy was scored from 0 to 5, 0 being totally unsuccessful, 5 being very highly successful (Table 5-1).

The cost was defined as the expense of implementing the strategies in an attempt to reach the objective. Cost was scored from 0 to 5, 0 being no cost, 3 about average (or current) costs for managing the park, and 5 being above average costs (Table 5-1).

The social, ecological, economic, cultural and agency/political consequences and benefits were assessed for each strategy. These were scored from -3 to 3, -3 having very high consequences, 0 no consequences and no benefits, and 3 having very high benefits (specific details for the assessment in Appendix 5). Economic consequences are those economic impacts on the surrounding communities, for example, loss of tourism (Table 5-1).

This procedure was then undertaken for Lamington, Mount Barney and Main Range National Parks. A group conversation on the practicality and validity of the framework and process for decision making about climate change impacts were also discussed.

Averages were calculated for probability of success, cost and each of the 5 implications (i.e. social, ecological, economic, cultural and agency/political) for each value on each park, for each of the six management strategies. The average costs and probabilities of success were assessed for each park value to calculate strategies for feasibility (i.e. low cost/ high probability of success = very good; high cost/ low probability of success – very poor). These were depicted with scattergrams (cost – x axis; success – y axis). The averages for each strategy's implications were compared for each value across the parks to evaluate where the possible benefits and consequences may lay.

### **5.1.2 Results**

The 'do nothing' approach scored the highest probability of success (5) in all parks and values, i.e. this will always succeed in achieving the outcome of accepting the consequences of no action, including any losses. It also received the lowest cost (0), i.e. will not require any resources to carry out an action of 'do nothing'. However, doing nothing resulted in very high negative consequences and no positive benefits for social, ecological, economic, cultural and agency/political implications.

There were no economic benefits for any of the stream dwelling frog or cool temperate forest values for any of the strategies. The only economic benefits were for walking tracks, primarily the preventing change focused strategies for Springbrook Figure 5-1).

The results of the perceived implications for the other strategies are considered below for each of the three values.

**Table 5-1 Management options**

|  |
|--|
| Feasibility  |
| Probability of success - On a scale from 0 to 5, score your opinion of how successful this management strategy would be.   |
| 0 Not successful at all, not achieving any management outcomes   |
| 5 Total success achieving management outcomes  |
| Cost - On a scale from 0 to 5, score your opinion of how costly this management strategy would be  |
| 0 No cost involved   |
| 1 Very low cost, very small amount of dollars, well below what would be required for normal operating budget   |
| 3 Average cost, general amount spent in a normal operating budget for ongoing management   |
| 5 Very high cost – large amount of dollars, well above general amount spent in a normal operating budget   |
| Consequences and benefits  |
| Social - On a scale from -3 to 3, score your opinion on how socially acceptable or unacceptable this management strategy would be  |
| -3 Largely, socially not acceptable, i.e. unacceptable to the public and stakeholders  |
| 0 No consequences, no benefits   |
| 3 Provides high social acceptability   |
| Ecological - On a scale from -3 to 3, score your opinion the how detrimental or beneficial for the value this management strategy would be (i.e. not restricted to this particular park, the value may be found in other protected areas and a decrease or loss in this park has/hasn't substantial impact overall). |

- 3 Is detrimental to the value overall
- 0 No positive or negative detriment to the value
- 3 Has provided great benefit to value

---

Economic - On a scale from -3 to 3, score your opinion on how much impact economically this management strategy would be. This is not the cost of the management strategy, this may include for example, the cost of a community's reliance on the park either through tourism, access to resources.

- 3 Has a large negative economic impact, particularly on the local area or region that rely on the protected area
- 0 No positive or negative economic impact
- 3 Provides a benefit or an increase in the economy of the local area or region

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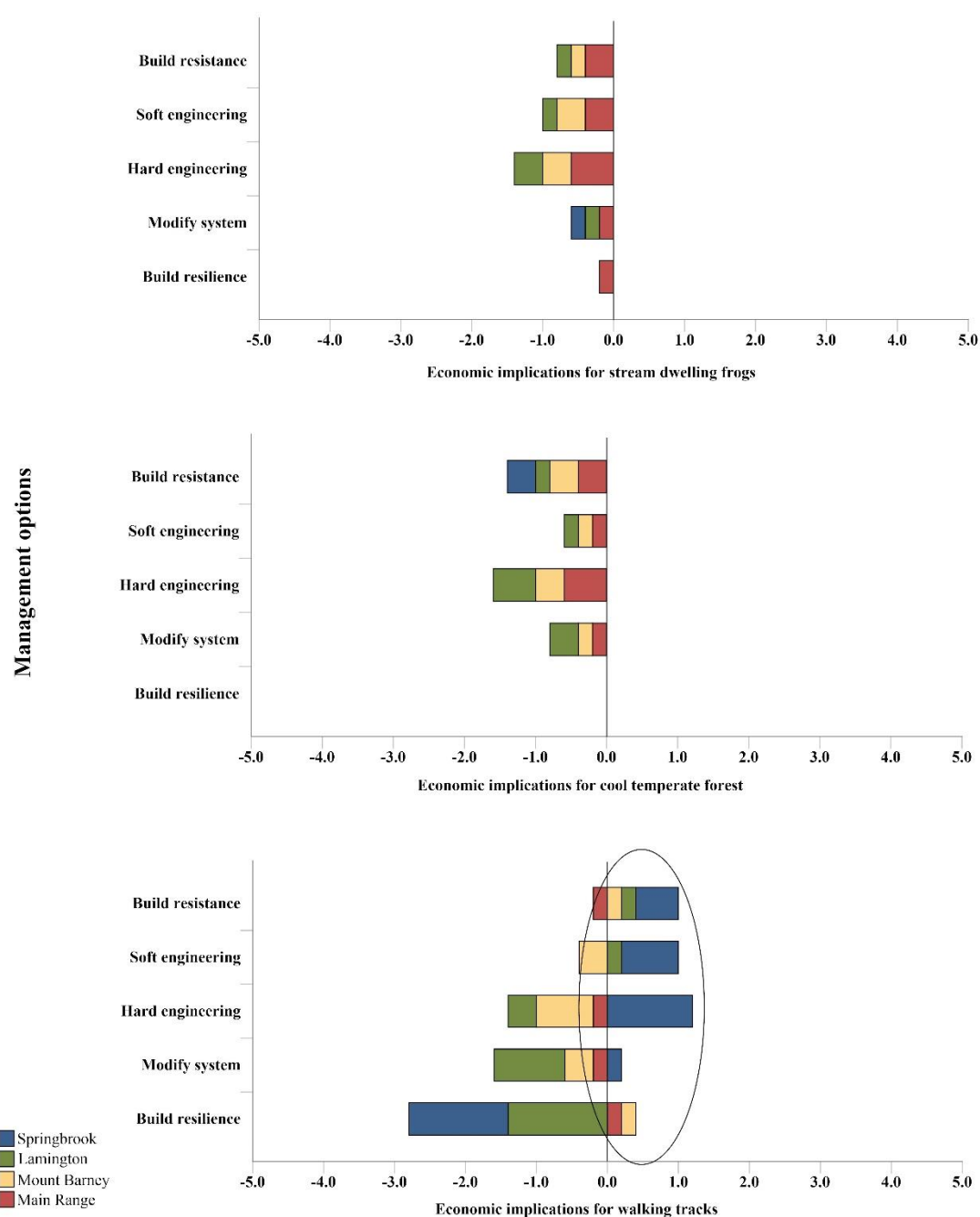
Cultural - On a scale from -3 to 3, score your opinion on how culturally acceptable or unacceptable this management strategy would be (indigenous and/or historic cultural significance)

- 3 Loss of cultural assets, not culturally acceptable at all
- 0 No impact on cultural values, neutral cultural acceptance
- 3 Cultural values have benefited and/or there is a large cultural acceptance

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Agency/political - On a scale from -3 to 3, score your opinion on how politically acceptable or unacceptable this management strategy would be, and the impact on the Government and managing agency.

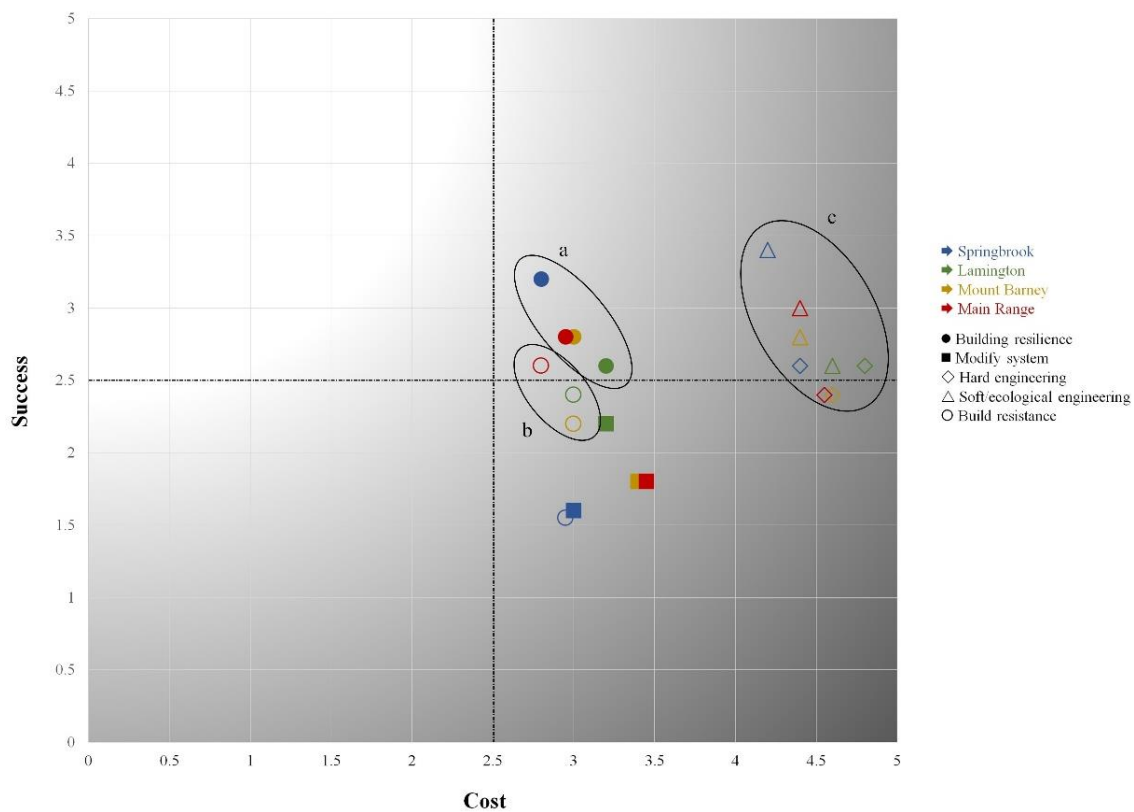
- 3 High, negative impact, politically unacceptable, may be breach of policy or legislation
  - 0 No impacts, politically acceptable
  - 3 Provides a benefit to the Government and/or managing agency
-



**Figure 5-1 Economic implications (consequences and benefits) for management strategies for stream dwelling frogs, cool temperate forest and walking tracks. Circle depicts the highest perceived economic benefits, primarily preventing change strategies on Springbrook National Park.**

### 5.1.2.1 Stream dwelling frogs

No parks rated high success/low cost for feasibility. All four parks rated high success/high cost for building resilience (a, Figure 5-2). Lamington, Mount Barney and Main Range rated average feasibility for building resistance (b, Figure 5-2). Hard and soft engineering were the most costly being well above average with average success rate (c, Figure 5-2).

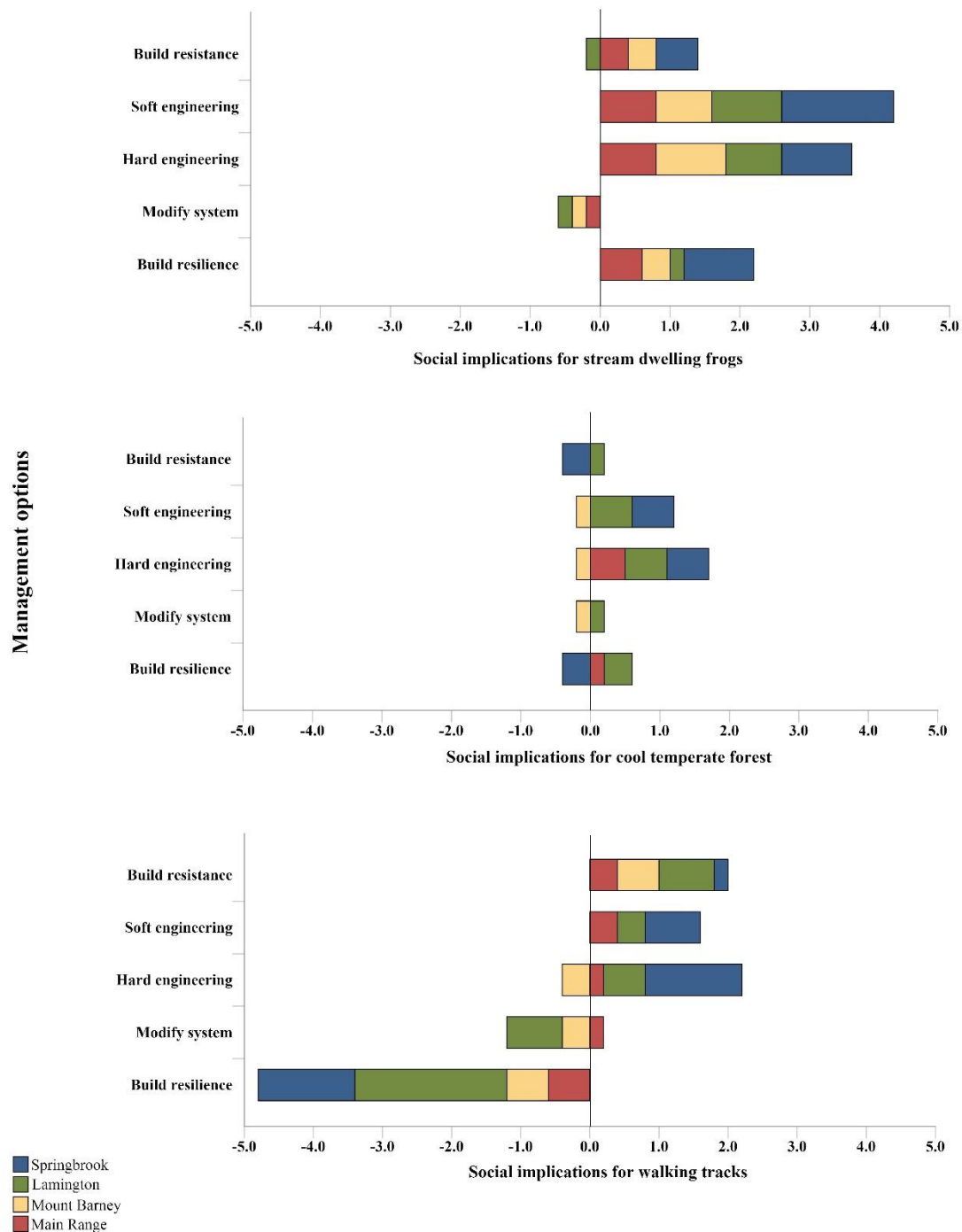


**Figure 5-2** Graph displaying feasibility of management strategies (average probability of success against average cost) for stream dwelling frogs. The white area shows the highest feasibility (i.e. high success/low cost). Building resilience (a) appears to provide the highest rates of success with the lowest cost, followed by building resistance (b), hard and soft/ecological engineering are very high in cost (c).

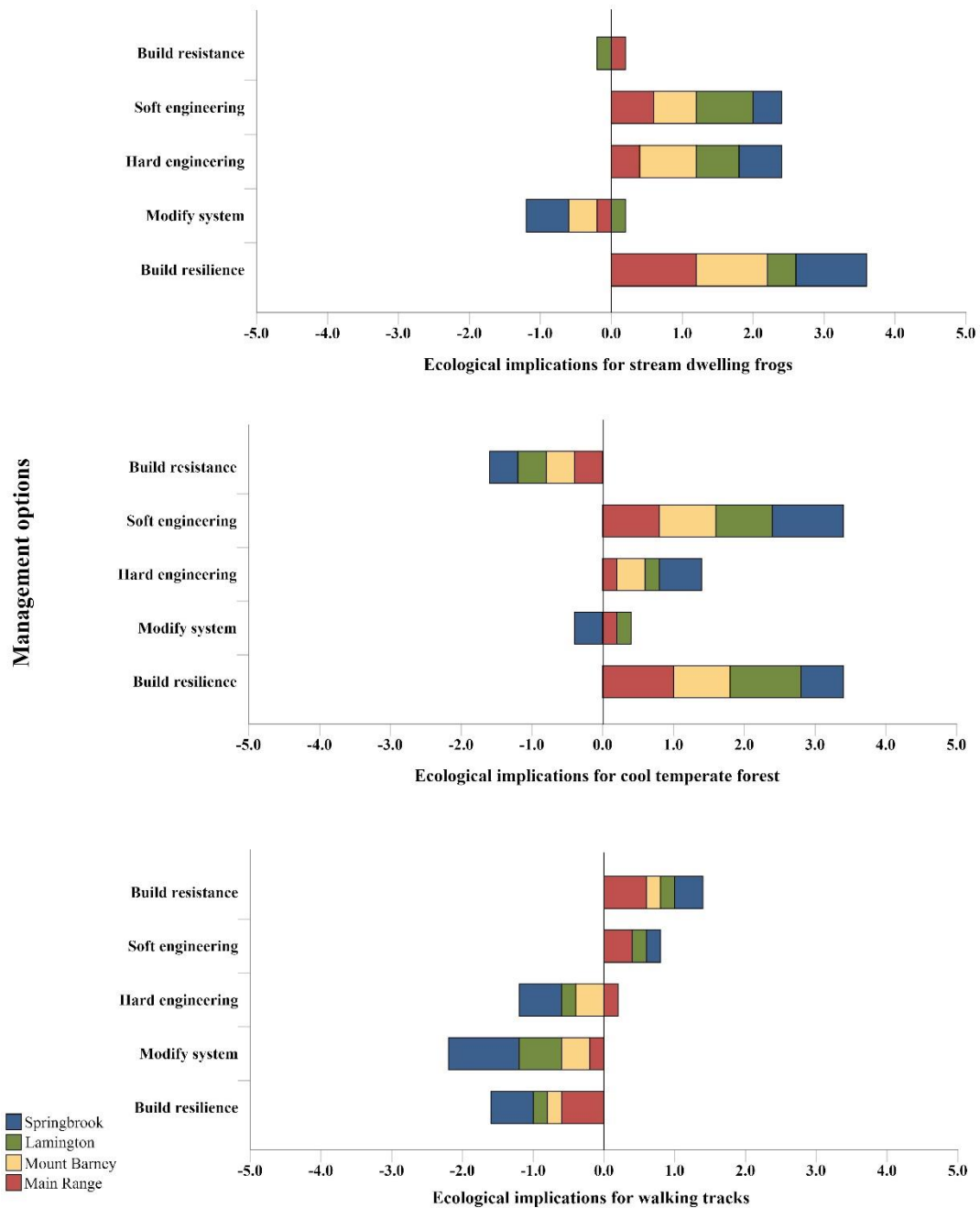
Soft and hard engineering showed the highest social benefits for all four parks, and building resilience for Lamington and Springbrook (Figure 5-3). Building resilience showed the highest ecological benefit for all four parks, as well as soft and hard engineering on Mount Barney and Main Range (Figure 5-4). Soft engineering and building resilience showed the most benefit for the managing agency and political implications and no negative consequences (Figure 5-5). Modifying the system showed some minor social and ecological



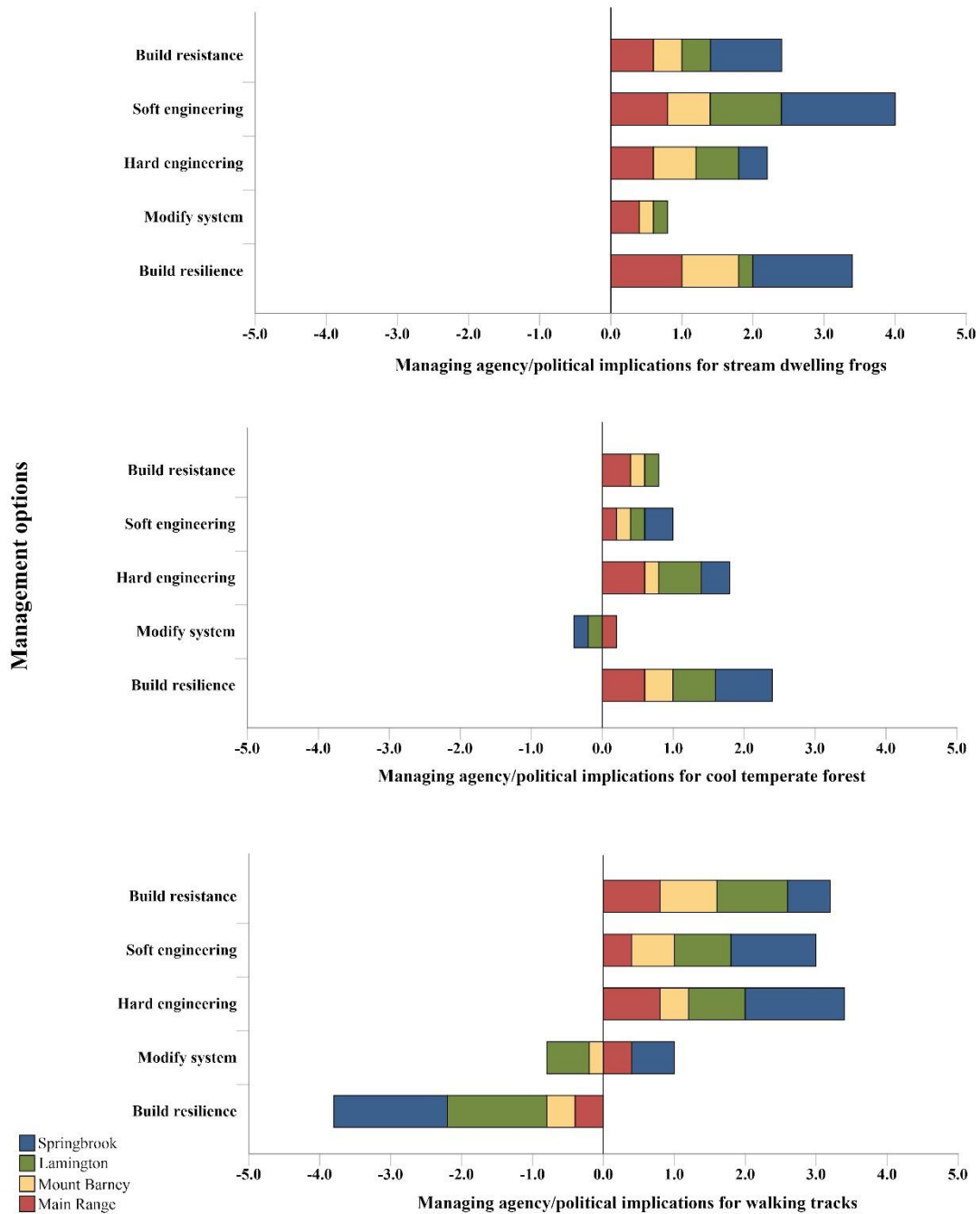
consequences (Figure 5-3 and Figure 5-4), and soft and hard engineering as well as modifying the system indicated minor cultural consequences (Figure 5-8).



**Figure 5-3 Social implications (consequences [-] and benefits [+]) for management strategies for stream dwelling frogs, cool temperate forest and walking tracks.**



**Figure 5-4 Ecological implications (consequences [-] and benefits [+]) for management strategies for stream dwelling frogs, cool temperate forest and walking tracks.**



**Figure 5-5 Managing park agency and/or political implications (consequences [-] and benefits [+]) for management strategies for stream dwelling frogs, cool temperate forest and walking tracks.**

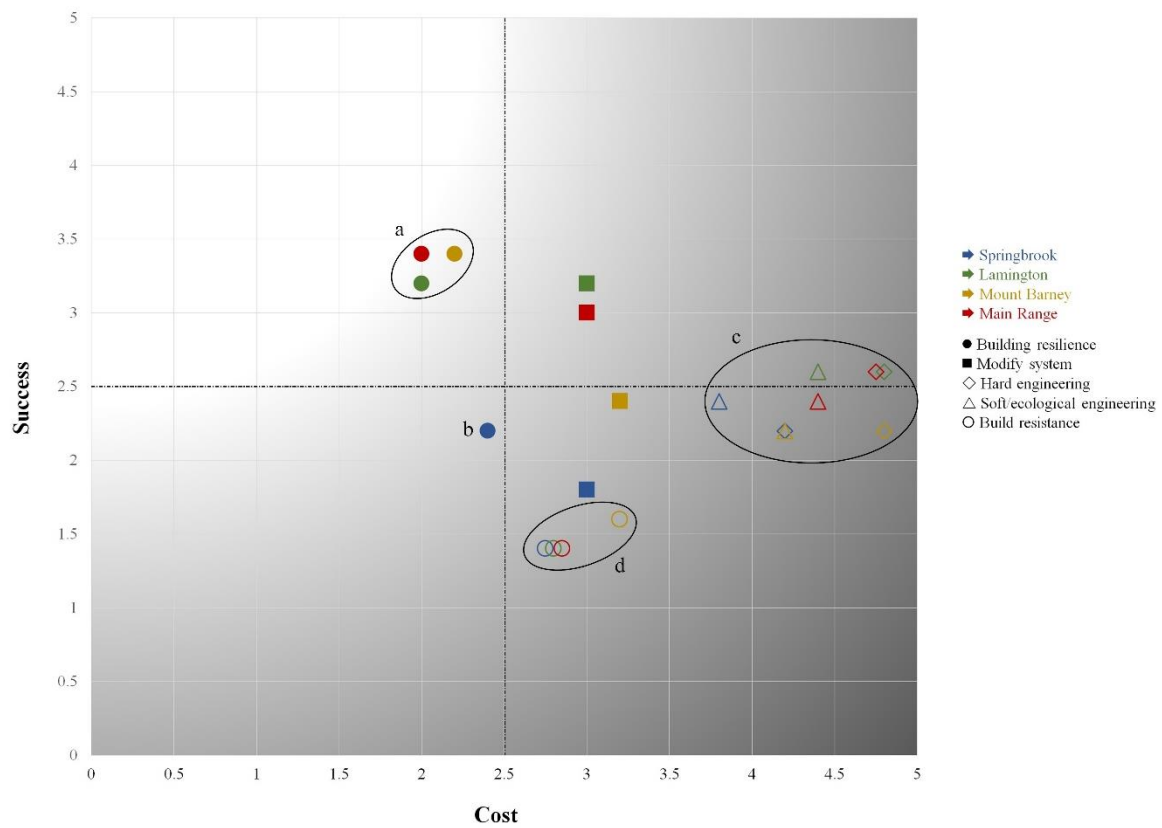
#### **5.1.2.2 Cool temperate forest**

Strategies to accept and manage transformations under climate change (i.e. building resilience) for Lamington, Mount Barney and Main Range resulted in high success/low cost (a, Figure 5-6); Springbrook however showed low success/low cost (b, Figure 5-6). Strategies to prevent or halt the changes with hard or soft engineering were higher in cost with average success (c, Figure 5-6). Building resistance strategies on all parks resulted in high cost/low success (d, Figure 5-6). Hard and soft engineering showed the highest social benefits for managing cool temperate forests (Figure 5-3). Indirect intervention and building resilience showed the highest ecological benefits (Figure 5-4), and building resilience followed by hard engineering revealed the most benefit for the managing agency and political implications (Figure 5-5). Springbrook showed the highest negative social consequences, i.e. building resistance and resilience (Figure 5-3), building resistance on all four parks showed the most ecological consequences (Figure 5-4), while hard engineering and building resistance showed the highest cultural impacts (Figure 5-8). Lamington and Springbrook showed some negative implications for the political and managing agency for modifying the system (Figure 5-5).

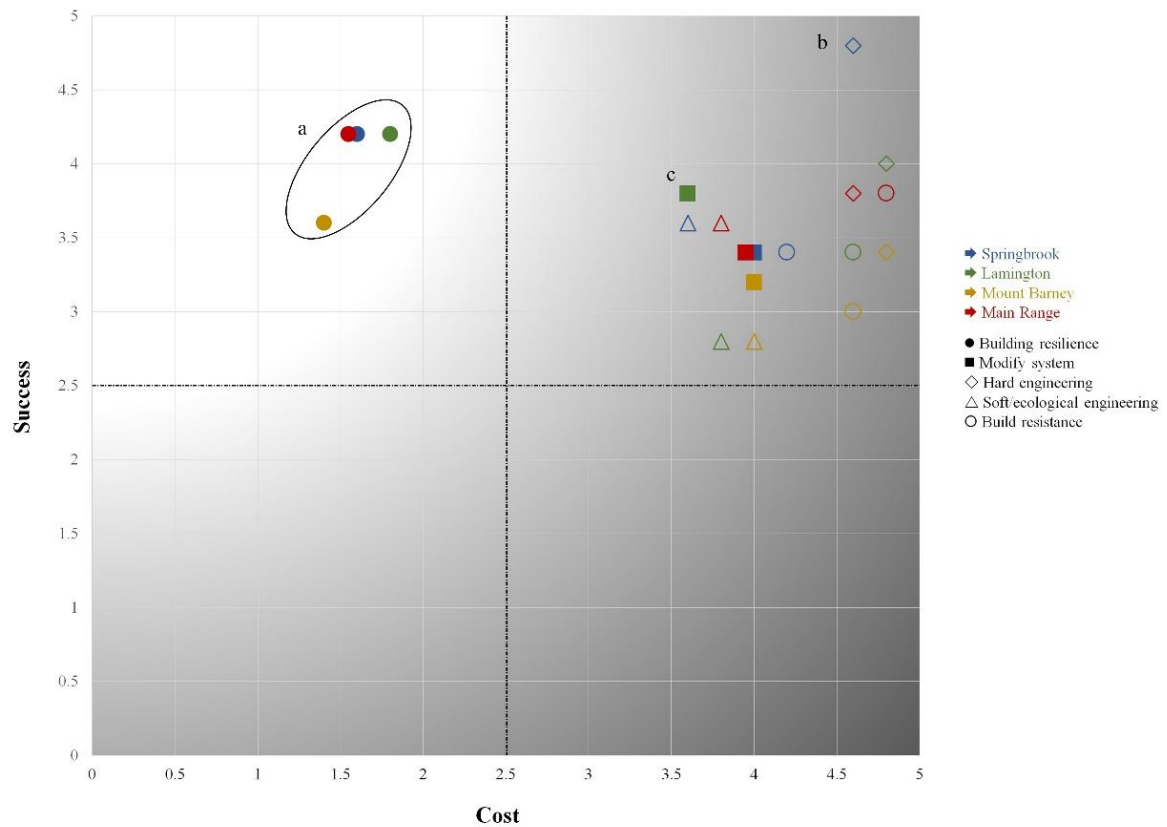
#### **5.1.2.3 Walking tracks**

Building resilience was a highly feasible strategy on all four parks (i.e. high success/low cost) (a, Figure 5-7). Springbrook showed a very high success, but very high cost for hard engineering (b, Figure 5-7). Lamington resulted in a high rate of success and high cost for modifying the system (c, Figure 5-7). All other strategies resulted in high success/high cost (Figure 5-7).

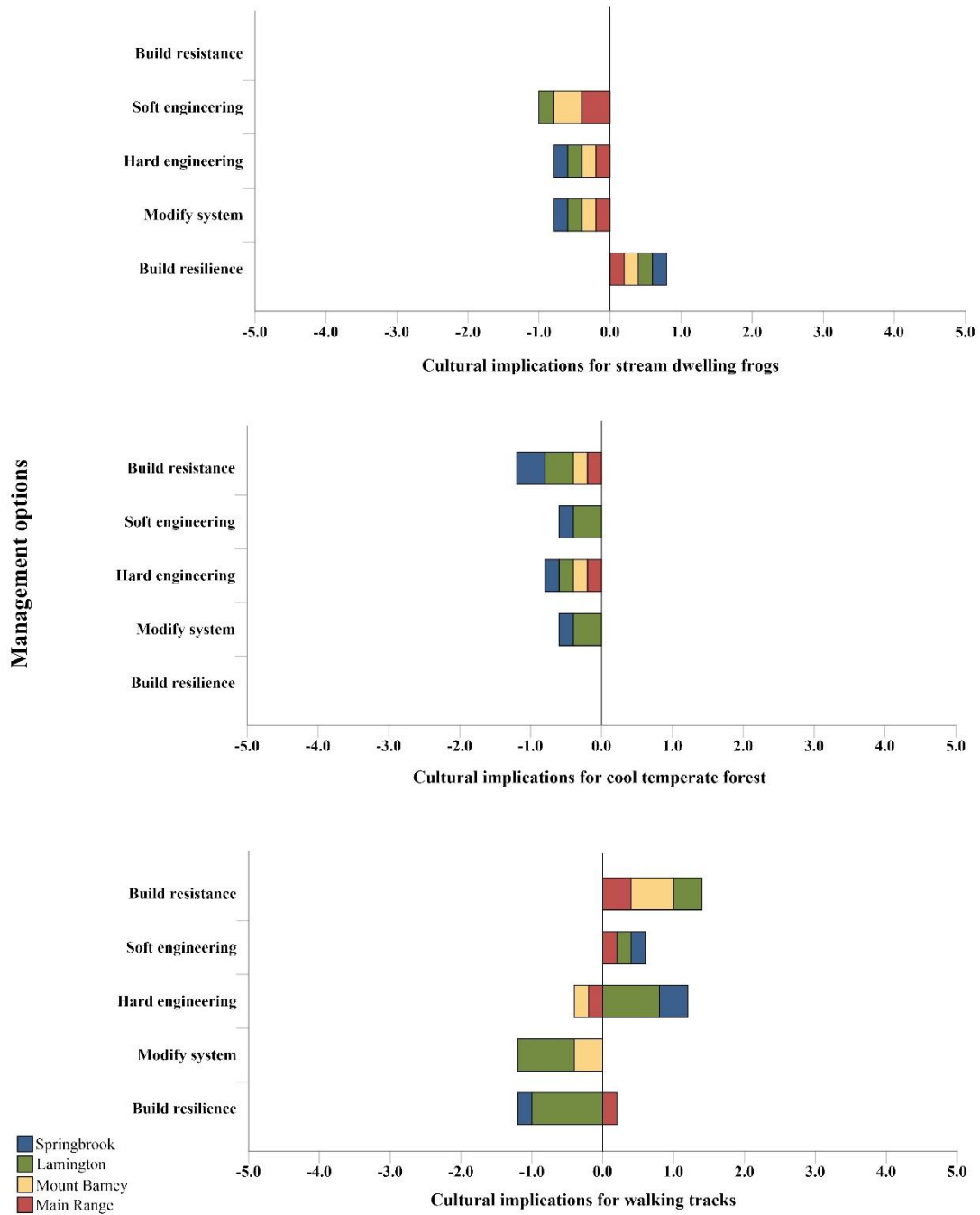
Building resilience showed very high negative social and managing agency/political implications (primarily Lamington and Springbrook) for walking track strategies whereas building resistance, hard and soft engineering showed a benefit (Figure 5-3 and Figure 5-5). Hard engineering, modifying the system and building resilience showed some ecological impacts while building resistance and soft engineering showed some benefits (Figure 5-4). Negative cultural consequences were seen for the accepting change strategies of modifying the system and building resilience for Lamington, while the preventing change focused strategies showed some benefits (Figure 5-8).



**Figure 5-6 Graph displaying feasibility of management strategies (average probability of success against average cost) for cool temperate forest. The white area shows the highest feasibility (i.e. high success/low cost). Building resilience for Lamington, Mount Barney and Main Range showed high success/low cost feasibility (a) and Springbrook showed low success/low cost hard (b). Soft/ecological engineering were high in cost (c), and building resistance showed low success/high cost (d).**



**Figure 5-7** Graph displaying feasibility of management strategies (average probability of success against average cost) for walking tracks. The white area shows the highest feasibility (i.e. high success/low cost). Building resilience showed the most feasible management strategies (i.e. high success/low cost (a), Springbrook rated very high success/very high cost for hard engineering (b). Modifying the system for Lamington resulted in a high success/high cost (c).



**Figure 5-8 Cultural implications (consequences [-] and benefits [+]) for management strategies for stream dwelling frogs, cool temperate forest and walking tracks.**

## 5.2 Discussion

The methods and results in this chapter provide a clear and definitive process contributing to decision making of protected area management in response to climate change associated impacts. this approach draws on scientific and expert opinion to reduce and accommodate increasing uncertainty, assesses a range of strategies against each other to weigh up options, scrutinises a variety of influencing factors (i.e. economic, ecological, cultural, social and political), and provides decision makers with multiple options that can be applied to park management.

The approach provides a means to compare the cost against the probability of success to determine feasibility of possible park management strategies, however decision making straight forward answer concerned only with feasibility, management options also come with varying implications for park management. By comparing the feasibility with implications, park managers can get a general idea of the most probable management directions (Table 5-2), although the answer may not be straight forward.

A park value may have varying levels of importance depending on factors such as legislative requirements, resources, or community expectations resulting in different implications. For example, the ecological implications of stream dwelling frogs and cool temperate forests may be considered one of the more important aspects for these park values because they contribute to the parks' biodiversity and World Heritage listing. Although building resilience indicated a high ecological benefit for stream dwelling frogs, so did soft and hard engineering strategies (Figure 5-4) which may prove more beneficial on some parks. Likewise, with cool temperate forest (Lamington and Main Range), modifying the system (i.e. high success/med cost) showed very little ecological benefit.

Other values will have stronger connections to economic and political implications. There was a clear distinction in social benefits for managing tracks to prevent climate change impacts, particularly Lamington and Springbrook that are in close proximity to residential areas and large tourist nodes of the Gold Coast and Brisbane. For these values of the park, social and/or political positions most likely require more attention. Although building resilience appeared highly feasible, the negative social (Figure 5-3) and political/agency implications (Figure 5-5) were very high.



**Table 5-2 Analysis combining the feasibility (probability of success and cost) and implications of probable management options for the three values across all four parks. Green boxes show the management options which resulted in high feasibility and positive implications. Orange boxes show those management options that had either medium feasibility/positive implications or high feasibility/negative implications.**

|              |                  | Frogs       |              | CTF         |              | Tracks      |              |
|--------------|------------------|-------------|--------------|-------------|--------------|-------------|--------------|
|              |                  | Feasibility | Implications | Feasibility | Implications | Feasibility | Implications |
| Springbrook  | Build resilience | Med         | Positive     | Med         | Positive     | High        | Negative     |
|              | Modify system    | Low         | Negative     | Low         | Negative     | Med         | Negative     |
|              | Hard engineering | Med         | Positive     | Low         | Positive     | Med         | Positive     |
|              | Soft engineering | Med         | Positive     | Low         | Positive     | Med         | Positive     |
|              | Build resistance | Low         | Positive     | Low         | Negative     | Med         | Positive     |
| Lamington    | Build resilience | Med         | Positive     | High        | Positive     | High        | Negative     |
|              | Modify system    | Low         | Negative     | Med         | Negative     | Med         | Negative     |
|              | Hard engineering | Med         | Positive     | Med         | Positive     | Med         | Positive     |
|              | Soft engineering | Med         | Positive     | Med         | Positive     | Med         | Positive     |
|              | Build resistance | Low         | Negative     | Low         | Negative     | Med         | Positive     |
| Mount Barney | Build resilience | Med         | Positive     | High        | Positive     | High        | Negative     |
|              | Modify system    | Low         | Negative     | Low         | Negative     | Med         | Negative     |
|              | Hard engineering | Low         | Positive     | Low         | Negative     | Med         | Negative     |
|              | Soft engineering | Med         | Positive     | Low         | Positive     | Med         | Positive     |
|              | Build resistance | Low         | Positive     | Low         | Negative     | Med         | Positive     |
| Main Range   | Build resilience | Med         | Positive     | High        | Positive     | High        | Negative     |
|              | Modify system    | Low         | Negative     | Med         | Positive     | Med         | Positive     |
|              | Hard engineering | Low         | Positive     | Med         | Positive     | Med         | Positive     |
|              | Soft engineering | Med         | Positive     | Low         | Positive     | Med         | Positive     |
|              | Build resistance | Med         | Positive     | Low         | Negative     | Med         | Positive     |

Strategies to manage climate change impacts will vary across parks. For example, the economic implications of walking track management (Figure 5-1) for Lamington's 'accepting change' focused strategies (i.e. building resilience and modifying the system) differed from the other parks. Results also indicated Lamington's walking tracks would show an economic benefit from prevention-focused management strategies while other parks did not. Lamington is a popular park for commercial tourism and therefore managing the walking tracks to maintain them in good, or very good condition is important for the community.

There are a number of restrictive features that may place constraints on decisions such as climate change impacts not within a park manager's control. For example the cool temperate forest impacts that appear to be less manageable because of the direct effects of loss of cloud cover and moisture (Laidlaw et al. 2011b). Although hard engineering rated fairly high socially, ecologically and politically, this is a very expensive option with limited probability of success. Some success was believed to be achieved through building resilience and modifying the system to allow for change which had average costs. Doing nothing was socially and politically unacceptable; however, this may be an option for parks such as Springbrook where only 0.26% of Queensland's cool temperate forest is found.

Other restrictions such as social aspects influence decisions where higher priorities lie. The social and political consequences for Mount Barney and Main Range were not as high as Springbrook and Lamington, nevertheless does this make these parks any less important ecologically. QPWS's fire policy focuses predominantly on protection of life and property (Queensland Parks and Wildlife Service 2013), so parks such as Springbrook may receive more resources to manage fire due to close proximity of residential areas. Main Range and Mount Barney may have less impacts and easier to manage due to fewer residential properties surrounding the park, particularly for aspects such as fire where they can concentrate more on ecological burning.

Protected area management options are limited by resources (Leverington et al. 2010) which are often lacking; for example, where inadequate resources affect management of park infrastructure (Watson et al. 2014). Through assessment and prioritisation, redirecting resources to more serious threats can improve park management (Geldmann et al. 2015). Parks that are expecting or already experiencing high climate change impacts to walking tracks, particularly parks with vast track systems such as Lamington, may need to make

decisions about increased investment of resources if they desire to maintain tracks to certain standards under increasing climate change impacts (Chapter 4). Strategies for walking tracks across the Gondwana parks that were discussed amongst QPWS during the workshop included closing some tracks that are less-used and that are being severely affected by landslides and other major impacts. They discussed the option of doing nothing, allowing tracks to deteriorate but restrict use to visitors with more hiking skills who are seeking a more wilderness experience. This would allow resources for improved maintenance to be re-directed to more heavily used or valued tracks. Lamington's walking tracks also have a cultural value with many of the tracks being constructed during World War II and the Depression. Preservation of these as a cultural value should also be taken into consideration during decision making to ensure management and protection of all heritage values are undertaken, i.e. exploring strategies such as recording tracks prior closure or assessing implications in terminating management.

Given the various implications and restrictions for decision making for protected areas, how do managers develop optimal strategies? In order to adapt management to deal with these issues, the adaptive capacity of managing agencies must also be flexible in resource allocation and response to changes including revisiting conservation goals (Armsworth et al. 2015). Many protected areas will benefit from a combination of strategies to provide a higher chance of success in meeting management objectives by not 'putting all your eggs in one basket' in a manner of speaking. A diversity of management strategies lowers the risk of negative changes (Perry 2015) because having just one strategy may fail to meet management objectives (e.g. decrease in population or loss of a species), and reduces that chance of maladaptation. A combination of strategies can also help satisfy a range of implications for example, a low cost strategy with high chance of success may not fulfil social expectations and by implementing a range of strategies this may be satisfied (Perry 2015). For example, a balance could be achieved by implementing building resilience and hard and soft engineering for the walking tracks could fulfil some of the social obligations.

Protected area management commonly occurs within a social environment, and decision makers frequently deal with community expectations in setting management objectives. Quite often these expectations may differ from managing agencies or ecological objectives. Individuals or groups of individuals may perceive the same situations in very different ways because of a wide variety of factors such as social influences, past experiences, held values,

norms and beliefs, knowledge and motivations (Bennett 2016). A practical approach to a decision should consider all these factors to increase the probability of community support and success of management objectives. Tools such as this decision making framework incorporates all these factors into decision making but may also help communicate those trade-offs to the community and assist in this disparity. This may be beneficial in conservation agencies seeking to introduce changes in community expectation about successful outcomes to alleviate some negative implications such as changes in values they perceive as a loss.

### **5.3 Conclusion**

Managing protected areas for climate change is a complex process. Decision making and management strategies must be relevant to a protected area's context and implications. It must take into consideration not just possible impacts, but must be considered within a socio-ecological structure for park management to be most effective. A wide range of management strategies should be assessed to take account of their various implications (Table 5-2) before decisions about future management are made. Climate change will alter how protected areas currently appear and management must adjust to how they may look in the future. This may involve considering accepting and managing for probable changes, but also seeking to avoid impacts on those values that warrant protection.

It is important that climate change management is incorporated into an adaptive management framework (Lawler et al. 2010) and that agencies adopt a flexible adaptive approach to making decisions. The decision to move forward with any particular strategies should not be a final outcome. Over time, political environments change, local communities evolve, species and ecosystems migrate or transform; and as monitoring takes place with better information gathered, other strategies may become more viable and a change of management objectives may be needed.

## Chapter 6

### Discussion and conclusion



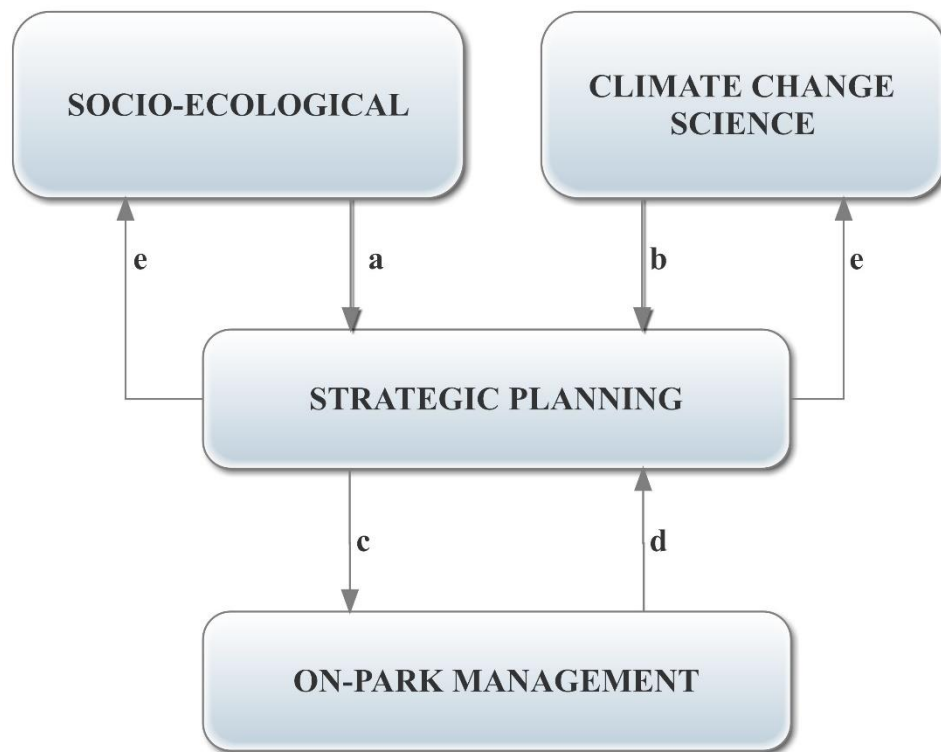
Plate 6 – Queensland Parks and Wildlife Service sign, Lamington National Park

**‘We will be known forever by the tracks we leave’ –  
Native American Proverb**

## 6.1 Overview

Protected areas may look very different in the future due to changes in climatic conditions. Current on-park management will have to respond to climate change associated impacts and therefore park managers must be prepared for change. The intention of this thesis was to develop a framework to assist protected area managers in adapting on-park management to climate change. It developed a method to link climate change science and socio-ecological aspects to on-park management so strategies grounded in science can be implemented at a park level. It aimed to connect park management to strategic planning and science to encourage development of adaptation strategies and recommendations that are feasible and practical for park management. It has accomplished this by examining a number of factors that play a role in effective protected area management, providing tools and methods to link these together, and incorporating them into a structure to be applied to a park or range of parks for long term objectives of conservation under climate change.

Figure 6-1 revisits the conceptual model presented in Chapter 1 illustrating the relationships, represented by the letters a-e (Figure 1-1, Figure 6-1), between science, socio-ecological factors and on-park management via strategic planning which need to be strengthened in order to adapt protected area management for climate change. This thesis answered three key research questions (Chapter 1) aimed to address the weaknesses in these relationships. A survey of the community and park neighbours in Chapter 3 was conducted to understand the socio-ecological environment in which the protected areas are managed (a, Figure 6-1). Bayesian belief networks assessing the climate change impacts and park management implications on stream dwelling frogs and cool temperate forest (Chapter 4) presented a modelling method to gather and combine existing data from multiple sources such as scientific information and expert knowledge to inform strategic planning (b, Figure 6-1). The decision making process in Chapter 5 used a scenario technique to incorporate captured climate change science and socio-ecological information into on-park management strategies (c, Figure 6-1). Surveys of and interviews with QPWS staff (Chapter 3) as well as BBNs for walking tracks (Chapter 4) provided two mechanisms for gathering on-park data and information to inform and adapt strategic planning for climate change (d, Figure 6-1). Outcomes of the decision making process (Chapter 5) can then be used for more targeted monitoring activities to guide relevant climate change and socio-ecological research (e, Figure 6-1) which will better inform protected area management and decision making.



**Figure 6-1 Conceptual model revisited from Chapter 1. Letters (a-e) represent the strategies applied in this thesis to address those gaps in the relationships (a – Community and neighbour survey, b – stream dwelling frog and cool temperate forest BBNs, c – decision making framework, d – QPWS interviews and survey, walking track BBN, e – outcomes of the decision framework).**

The process used throughout this thesis presents a course of action that protected area managers can use to better prepare their parks for the threats and impacts of climate change. It fills a gap in *in situ* park management approaches to support long term goal setting and adaptive management. Extensive analysis conducted on integrated values assessments and future climate predictions is helpful but not always essential. Effective adaptation to climate change can begin to be undertaken with existing data and information park managers and other experts already hold. This approach also begins to bring attention to capacity building for park managers in making different decisions.

To draw together the findings in this thesis, this chapter reflects on how the findings address the three research questions (Chapter 1). It then discusses the implications of these conclusions and their limitations and lastly provides direction for future research.

## **6.2 How can socio-ecological attributes be recognised and understood for more effective protected area planning and management under climate change?**

Characteristics of the local community and park neighbours can be better understood by developing and strengthening those links between ‘socio-ecological’ and ‘park management’ (a and d, Figure 6-1). To accomplish this, a survey of the community, park neighbours and QPWS park managers was developed and carried out (Chapter 3).

The community and park neighbour survey gave an understanding of the socio-ecological characteristics of the region. This is an important step to improving park management adaptation to climate change by understanding people’s perceptions and values relating to climate change and where significant differences lay. The survey showed that most participants were very highly or highly concerned about climate change and that a high percentage of people ranked the natural environment as a concern. The survey also revealed the community’s lower concern for protected areas. Likewise, it reveals other higher concerns such as water supplies and agriculture. This information can give park managers a sense of how important the community values the natural environment and protected areas compared to other aspects of their lives. Understanding the characteristics of a socio-ecological environs will help identify core drivers of social impacts, assist development of park management goals, and influence a park’s capacity to adapt to climate change (Cumming et al. 2015).

Comparing those values and perceptions with the park agencies objectives and park staff views reveals information about similarities and significant differences between park staff, the community and park neighbours. By understanding these relationships, effective park management strategies for climate change may be developed. Identifying climate change adaptation issues where the community and park managers share similar views will support targeted strategies. The Scenic Rim case study (Chapter 3) indicated a number of



commonalities between QPWS, park neighbours and the community. This signifies a high probability of implementation of compatible climate change adaption strategies on and around the parks, for example the similar views in regards to the threat of weeds (Chapter 3). This provides a solid foundation and direction for QPWS to begin working with neighbours on issues such as weed incursions and will assist park managers in tailoring strategies to improve effective and efficient use of resources.

Differences in values and perceptions may inhibit protected area climate change adaptation, for instance conflicts over park management, and can make it difficult to gather community support for park management objectives. Significant differences in perceptions about introduced animals were found in the analysis (Chapter 3) and results showed this difference increased the closer a person lived to a park. This would indicate a higher probability of conflicts involving issues associated with pest animals, particular boundary and neighbour disputes. By understanding this, park managers can customise strategies differently for the community and park neighbours.

Fire and fire management appear to be one of the most significant issues facing park managers in adapting management for climate change. In Australia, fire is a major driver of ecosystem change (Lucas et al. 2007; Penman et al. 2011), therefore is a considerable focus of park management, and possibly one of the key issues to deal with in climate change adaptation. Park managers will increasingly need to deal with differences in people's beliefs and ideals about the desired outcomes of fire management; surrounding land uses imposing changes to fire management on park; and increasing priorities of protection of life and property for planned burning (Chapter 3). Early recognition of potential issues provides park managers with the ability to plan early and long term.

There are substantiated links between perceptions/values and behaviour (Winter & Lockwood 2005; White et al. 2008) and understanding people's beliefs can assist managers to influence their behaviour (Brown et al. 2010) both on and off park. This is important because some issues are not resolved through only a scientific or economic means (Harrison & Burgess 2000; Winter & Lockwood 2005). If these interactions between human behaviour and natural systems are misunderstood, predictions about policy outcomes may be misleading (Milner-Gulland 2012). Linking these values can support strategies that address external influences such as surrounding land use which has an influence on park values and management

(Borgstrom et al. 2012). Chapter 3 explored how local communities and neighbouring properties can influence a parks capacity to adapt to climate change, how communities manage their properties and how the types of land use affect climate change impacts and park management.

Springbrook was shown to be particularly susceptible to incursion of weeds from external sources (Chapter 4) with the headwaters of many of the park's streams on neighbouring properties, many with exotic garden plants.

‘Somewhere like Springbrook, sort of English tea garden type neighbour's [gardens] that have exotic plants like exotic ginger coming in from urban areas into the National Park’<sup>2</sup>

In order for park managers to achieve conservation on the park, they will need to influence behaviour and activities surrounding the park, and understanding neighbour values and perceptions will improve success and effectiveness of management strategies.

### **6.3 How can climate change impacts on protected areas be better understood at a park level?**

Strengthening the relationships between climate change science and planning (b, Figure 6-1) as well as on-park management and planning (d, Figure 6-1) will increase an understanding of climate change impacts at a park level. Incorporation of science into environmental management decision making processes has been limited and challenging (Cvitanovic et al. 2014b). Despite considerable amounts of research conducted for climate change impacts (Geyer et al. 2015), very little is implemented into planning and park management (Lemieux et al. 2011b; Lemieux & Scott 2011). This is due to impracticality, inappropriate purpose (such as ‘off-reserve’ focused strategies), considerable time or resource requirements, or research conducted not necessarily answering the questions park managers require (Pressey et al. 2007; Hannah 2011; Gillson et al. 2013; de Koning et al. 2014; Rannow et al. 2014).

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<sup>2</sup> Quote from QPWS staff (Chapter 3).

Chapter 4 developed a set of conceptual models and BBNs to bridge the gap between climate change science and planning (b, Figure 6-1). Conceptual models provide a graphic representation of the ecological system in a way that park managers and other stakeholders can clearly understand. It helps describe objectives or conservation targets, direct and indirect threats and any influencing factors on those targets (Margoluis et al. 2009), which for this application expresses the linkages and driving factors of climate change on a park value (Chapter 4).

Transforming the conceptual models into BBNs provided the means to convert expert knowledge into a quantifiable tool for decision makers. The BBNs in Chapter 4 set out the major drivers of climate change and threats to park values, then assessed how park management may influence those impacts to produce a range of suitable approaches to deal with them. They incorporate scientific knowledge using expert elicitation to provide a better understanding of the ecological system. It did not give definitive answers; climate change and modelling exhibit uncertainty, but the model outputs provided a useful process for capturing that information to reduce and accommodate increasing uncertainty in decision making.

The benefits of using one conceptual model with customised BBNs for individual protected areas is that it can be applied to a range of parks to assess how they are expected to respond to climate change impacts and park management as compared to each other. This is beneficial when making decisions for individual parks with a regional consideration where it may be inappropriate to apply the same strategy in all parks. The stream dwelling frog BBNs (Chapter 4) indicated that with substantial climate change, the frogs will be negatively impacted, and one of those major drivers is fire, i.e. the threat of wildfire. By applying individual BBNs to each park, it became clear that Springbrook and Main Range were more highly affected by fire than Lamington and Mount Barney. This provides direction for park managers to begin investigating why. For example, Springbrook and Main Range appear more vulnerable due to their shape (Springbrook is small and fragmented, Main Range long and narrow) (Chapter 4), vegetation (i.e. drier vegetation types on Main Range) (Chapter 4), or social implications (i.e. focus of wildfire protection of residential properties in close proximity to Springbrook more so than ecological objectives (Chapter 3). This can direct park management to place more focus on fire management on these two parks in regards to adaptation strategies for stream dwelling frogs, and also customise those strategies specifically for those vulnerabilities. Likewise, this information can direct monitoring and

research requirements specifically for those threats and effectiveness of management strategies (e, Figure 6-1).

The BBNs also showed that in some cases, park management may have very little influence on maintaining some park values in their current state, justifying the need for management agencies to begin thinking about managing for change. The cool temperate forest models (Chapter 4) are a good example. This ecosystem is reliant on cool temperatures and moisture, particularly orographic cloud cover, and had little response to park management strategies.

Unlike cool temperate forests, the walking track models (Chapter 4) showed a good response to park management. Again, the use of individual BBNs were able to show that different parks may respond differently to climate change impacts due to their vulnerability. For instance, the high sensitivity of Springbrook and Lamington National Park's walking tracks to impacts such as landslips. This suggests those parks may require increased on-ground management to maintain those tracks as climate change results in increased magnitude and frequency of storms.

Effective park planning also requires input from park management (d, Figure 6-1) and establishing communication links from park management and planning will facilitate exchange of information between park managers, scientists and other experts, and guide appropriate research and monitoring required for park management adaptation (e, Figure 6-1). A lack of communication may result in research being undertaken that is not practical for park management and planning. The interviews with QPWS (Chapter 3) revealed information about on-park management issues that can direct monitoring and research that will assist adaptation of management. For example, the contentious issue about prescribed burning to maintain open woodlands or allowing rainforest succession (Chapter 3), research could confirm the effects and outcomes of these management strategies to provide improved information to inform decision making. Furthermore, outputs of the decision making process (Chapter 5) can inform scientists and help direct research more appropriate by supporting park management. Research can then deliver significant, practical and legitimate solutions to management problems (Cook et al. 2013).

A strong component of this model (Figure 6-1) is strategic planning. This forms the link between science and on-park management and is heavily influenced by the governance structure it works within, guided by policy and legislation. Science and research concerned with climate change adaptation must take into account the governance frameworks because they set the rules for which values are focused on, which knowledge will be applied to decision making, funding mechanisms (Wyborn et al. 2016).

#### **6.4 How can climate change impacts and socio-ecological attributes be incorporated into decision making and adaptive management of protected areas?**

The data and knowledge acquired from Chapters 3 and 4 was then incorporated into on-park management (c, d and e, Figure 6-1) by developing and testing a strategic decision making model for adapting park management for climate change associated impacts (Chapter 5). The model does two things; firstly, it provides a process to incorporate social information (Chapter 3) and BBN data (Chapter 4) into a strategic decision making process, and secondly it captures on-park data and knowledge using expert elicitation to support planning and monitoring.

The relationship between planning and on-park management (c, Figure 6-1) is strengthened by the decision making method which provided a scenario style of analysis whereby park planners and park managers can score a range of park management strategies (Chapter 5) against criteria based on their existing knowledge and with data and learning from external sources such as the surveys, interviews and BBNs (Chapter 3 and 4).

The stream dwelling frog and cool temperate forest BBNs (Chapter 4) captured knowledge from experts (amphibian ecologists, plant ecologists with expertise in rainforests, fire management), and were able to interpret their knowledge into a format for practical use by planners and park managers. For instance, the outcomes of the stream dwelling frog BBNs could inform decision makers about what climatic drivers of change each park was most sensitive to (Chapter 4). For example, Springbrook's sensitivity to wet breeding habitats and surrounding land use can assist decision makers in understanding the ecological implications across possible management strategy options (Chapter 5).

It is important that other factors (i.e. social, economic, cultural and agency/political) are considered as part of the decision making process in addition to ecological implications because park governance is influenced by all these factors. The decision making approach (Chapter 5) incorporated a scoring system to assess social implications across a range of management options. Planners and managers scored this from both their own knowledge and data from Chapter 3. Results indicated that visitor park opportunities, for example walking tracks, had negative consequences for ‘accepting change’ focused objectives, particularly building resilience strategies such as reducing management to maintain tracks at a lower standard, or changing track condition requirements. Although building resilience was estimated to be the lowest costs, it may not be the most appropriate because of these other implications and decision makers may have to choose costlier options.

Chapter 4 presented a method for obtaining this information for walking tracks through carrying out a workshop with QPWS staff to gather on-park knowledge (d, Figure 6-1). Park management staff such as park rangers have extensive knowledge about walking tracks including appropriate management, track classifications and standards, impacts and assessment, current track condition, and condition trends. The walking track BBNs were able to capture that park ranger knowledge in a systematic manner of all four parks across the region by using set criteria (Appendix 5) for objective reporting. This is important where regular monitoring and reporting into park planning does not occur. This provided a process for park planners to become more informed about on track management, condition and trends to be incorporated into the decision making process in Chapter 5.

## **6.5 Implications for adapting protected area management for climate change**

The method used in this framework can be incorporated into many existing systems of protected area management. Most current protected area management involve some process of decision making which could be adapted to accommodate this decision making framework. Many protected area management agencies already employ a risk management style of decision making that can be combined into adaptive management and provide a classification of response options (Rannow et al. 2014). There are also already a number of current tools of protected area management that are relevant for this framework and can easily be adapted for climate change strategies such as invasive species control, native plant restoration, captive breeding and prescribed burning (Mawdsley 2011).

The method employed here is appropriate for adaptive management, which is now considered ‘best practice’ for protected area management (Hockings et al. 2006; Dudley et al. 2010). It improves the understanding of both the social and ecological system for incorporation into management as highlighted by the use of the surveys and BBNs. It provides for adjustment of strategies to adapt to new park conditions through the monitoring feedback loops to protected area management, feeding back into the decision making process (Chapter 5). It integrates science into park management by use of expert elicitation in the BBNs. It also provides a way of continued park management where there is still a lack of understanding in the system. This approach therefore is not restricted to managing under climate change and can be applied to a variety of situations where park managers face difficult decisions.

This method involved park staff through every step of the process. It provided an exchange of information regarding climate change projections and impacts (both current and future) to their parks, park vulnerabilities and their adaptive capacity, and management options. A managing agency’s staff must be fully engaged through knowledge and desire to implement those actions (Welch 2005). Disregard for park managers and staff during planning may lead to a lack of acceptance by managers (Geyer et al. 2015) and the development of impracticable strategies by scientists and planners.

#### **6.5.1 Implementation into protected area management**

There appears to be a lack of capacity for governments worldwide to implement climate change adaptation options (Lemieux & Scott 2011). This may be due to lack of resources, political reluctance to change, static regulatory frameworks, or complex processes (Lemieux et al. 2011b; Geyer et al. 2015). Likewise, if a process put forward appears to be very complicated or mathematical, they are less practical for managers faced with many decisions (Fischman et al. 2014) and may be the cause of why many methods do not get implemented. The proposal put forward in this thesis is designed to be simple, efficient and easily integrated into current management and planning systems with available data and information. This was supported by one of the QPWS officers during the decision making process (Chapter 5).

‘I think having a process like that where you can just go through it without too much effort using a bit of local knowledge and a bit of judgement as a planner and land manager, you can really improve the quality of decision making.’<sup>3</sup>

The process will only be useful if recommendations emerge from the process, are assessed and adaptation options embraced and implemented. This activity assists managers to develop a range of strategic management directions to tackle climate change as they relate to park values, for example a range of hard and soft engineering options for walking tracks (Chapter 5). Understanding the implications and being presented with a range of management options provides an informed, objective approach in deciding on the most appropriate strategies. A range of strategies allows for a choice of outcomes reducing vulnerability (Perry 2015). Implementing a number of strategies will also provide a greater amount of knowledge through monitoring, faster learning from adaptive management, and may afford higher security in conserving and managing those values.

There will need to be some adjustments in protected area management for these procedures to be incorporated and implemented. A change of organisational culture may be required for many protected area managing organisations by managing for change rather than persistence, contradicting historic park management objectives of maintaining current values in static parks. Governing bodies will need to begin to accept that changes are imminent and will need to begin making more rigorous decisions including proper consideration of doing nothing and triage options (Chapter 5). An increase in adaptive capacity is required with many current structures inadequate to do this where barriers such as policy and legislation, resources, research and monitoring, and jurisdictional obstacles exist (Lockwood et al. 2012; Lemieux et al. 2013; Dutra et al. 2015).

Commitment will also be required by managing agencies to initiate long-term planning. Climate change will have an influence in the distant future and its impacts are not always immediate. Currently, the majority of protected area management planning is short term, for example in Australia, generally 5 or 10 years. This may have been suitable in the past,

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<sup>3</sup> Quote from QPWS staff (Chapter 5).



however climate change requires longer term planning. A minimum of 50 years has been suggested (Hannah 2003).

There will always be variability through time in policy and legislation as a reflection of changes in government and managing agencies. This may result in changes to government priorities and/or resources and have bearing on their commitment. However, a systematic process provides a transparent means by which protected area managers can justify decisions. This is particularly important in government institutions that are answerable to the public as suggested by a QPWS officer during the decision making process (Chapter 5).

‘Once you’ve made your decision and if you’re needing to justify it, whether it’s the minister or the public or whoever, then you’ve got your whole explanation there in front of you in order to quantify your decision making.’<sup>4</sup>

Like any form of effective management, there is a strong link between resourcing, management capacity and effectiveness (Leverington et al. 2010). For these methods to function effectively, it will require an injection of resources and support from the governing bodies such as park management agencies. In some cases, adaptation strategies will be necessary but costly. For example, the social and cultural implications of walking track strategies for hard and soft/ecological engineering were higher, but so was the costs (Chapter 5).

Although a commitment of increased resources will be necessary, implementation of these procedures will provide a more effective and efficient use than previous practices. Applying improved knowledge such as data from the surveys (Chapter 3) and the BBNs (Chapter 4) provides park managers with a better understanding the drivers of impacts to which they can prioritise their management strategies. More informed decision making will improve research and monitoring since it will be guided by objectives and strategies developed for adapting specific park management (Figure 6-1) and not undertaken for the sake of monitoring or an *ad hoc* basis (Abbott & Le Maitre 2010).

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<sup>4</sup> Quote from QPWS staff (Chapter 5).

## **6.6 Major contributions of this thesis**

The thesis demonstrates that good insights about future decisions can be made without masses of data. An approach like this can be used to help target research and /or monitoring where it may be most useful for decision making. For example, it can focus on particular parks and/or particular issues within a region that are more sensitive (i.e. wildfire threats to stream dwelling frogs on Lamington, Springbrook and Main Range NPs as per the sensitivity analysis results Table 4-2).

The approach contributes to vulnerability assessments which play an essential role in adapting management for climate change and developing effective strategies. The framework is a tool that can be applied to a species, habitat/ecosystem or place (i.e. specific protected area) and is an efficient and effective tool that for managers with limited modelling or scientific expertise can use to undertake vulnerability assessments.

This framework takes an approach that considers a wide variety of stakeholders.

Understanding the communities' values and perceptions will assist in reducing limiting factors associated with climate change adaptation and promoting successful conservation initiatives (Adger et al. 2009; Bryan et al. 2011). The framework considers external actors such as the community, park neighbours and scientists as part of the social-ecological environment being managed (Brugnach & Ingram 2012) and builds a bridge between these actors. The framework provides a solid basis for developing collaborative approaches to climate change adaptation planning through knowledge co-production and collaborative learning which plays an important role in social learning and adaptation to a rapidly changing environment (Roux et al. 2006; Armitage et al. 2011; Cvitanovic et al. 2015; Wyborn 2015a).

The approach herein is not designed to provide definitive answers for park managers to move forward with adapting park management, it builds the adaptive capacity of the managing agencies. The benefit of this framework is that it provides a process that forces decision makers to engage with issues and trade-offs when deciding how to adapt park management for climate change associated impacts. This assists park managers in better understanding the complexities of adaptation, raises their awareness about potential climate change impacts, and introduces a concept that agencies can implement within their own governance systems.

The framework also provides tools, and a means to use those tools that can be adapted and used for protected areas in other countries.

## **6.7 Directions for future research**

This thesis has developed a framework to assist protected area managers in adapting their planning and management of parks into the future under climate change. It has been applied to a regional set of national parks focusing on three key values where many advantages and positive outcomes were observed. There are still gaps in socio-ecological data in many areas of protected area management. Although researchers and governing bodies are slowly closing these gaps, considerable work is still required. For example, the decision making process used in this thesis (Chapter 5) employed protected area planners and park managers only. It would be wise to investigate further social implications such as interviewing or carrying out the process with external stakeholders such as non-government organisations or community groups. Different clusters of people have different perceptions, values and priorities. The method here was limited to one cluster of likeminded people with similar priorities. In order to gain a clearer understanding of the social implications, a wider audience should be engaged to offer a broader foundation of adaptation planning and increase probabilities of success of management strategies (Cvitanovic et al. 2014b; Knapp et al. 2014).

Economic implications should be further explored, for example the economic implications assessed for walking tracks were an estimate by protected area planners and park managers during the decision making stage (Chapter 5). Their results indicated some negative consequences for the ‘accepting climate change impact’ focused strategies (i.e. allowing for change and modification to tracks), particularly for Lamington and Springbrook. Information such as this should be confirmed with input from stakeholders such as commercial tourist groups with more knowledge and/or substantiated with external data.

Moreover, implementation of the decision making outcomes into on-park adaptive management through planning should be undertaken to trial management directions and assess acceptability of desired outcomes within the managing organisation and general community. A strong recommendation is testing the outcomes of the decision making process (d, Figure 6-1) by incorporating these results into adaptive park management of Queensland’s Gondwana national parks for these three key values. Development of a monitoring strategy

based on the outcomes of established management strategies is necessary. Monitoring of the Queensland Gondwana parks is generally undertaken by external researchers (i.e. universities) and agency monitoring is generally *ad hoc*. A strategy which establishes set outcomes would guide monitoring to answer the questions that park managers require for adaptive management.

This thesis focussed primarily on developing participatory approaches with managers to understand likely climate change impacts on parks in a region. Evaluation of the on-going impact on decision makers or decision making that arises from the processes developed fell outside the scope of the research. Questions that could be addressed in future research include how managers feel about managing for change and whether they accept the idea that change is not a loss.

The framework and its associated tools that focus on ecosystems, such as the BBNs for the Cool Temperate, focuses on ecosystem health and not necessarily change in ecosystem type because they use one ecosystem health indicator. A key point within the thesis is managing for change, and as ecosystem types will most likely transform under climate change, future modelling may include parametrising the models using concepts based on ecosystem change or ecosystem function, both valuable in their own right for society. Current models do not address this well and this leads to a knowledge gap in adaptation that requires further research.

#### **6.7.1 Implications for management of the Gondwana Rainforests of Australia (South East Queensland)**

Strategic management directions and strategies were not developed for the Gondwana parks, and their implementation not undertaken as part of this thesis as it was outside the scope of this research. Planning has to be part of government process and in order for the outcomes of this thesis to be implemented, they have to be adapted for the Queensland Government's frameworks, policies, directions and agendas.

Long term strategic management strategies should be developed for effective planning and park management, beginning with the outputs of the decision making process (Chapter 5). A review of possible management scenarios could assist managers on how to focus long term park management for climate change. It should address parks individually but must take into

account surrounding protected areas and have a regional focus (as per the BBN outcomes, Chapter 4). It should address each park's vulnerability to climate change impacts and their socio-ecological status. This should be done as a result of the BBNs (Chapter 4) which showed a variation in vulnerability to climate change impacts across the four parks. More importantly, strategies should feed into park management and operational plans to ensure implementation and adaptive management is undertaken (Figure 6-1).

A strategic plan of management for protected areas, with a regional focus is required. Park values need to be considered not on the park as a whole, but in many cases sections of parks with multiple strategies. It is important for the decisions to be considered not independent of other parks in the region, but also in regards to how protected area values (e.g. species, ecosystems and visitor assets) are positioned locally, regionally or even nationally. For example, a significant species expected to be highly impacted from climate change on a particular park may have a more stable and less impacted population on another park such as with the stream dwelling frog example (Chapter 4). Depending on the feasibility of management strategies, resources could be redirected elsewhere and less expensive strategies such as building resilience or even accepting loss of that particular population may be tolerable. Cool temperate forest is at its most northern extent in Queensland within Australia and there are considerably large areas of cool temperate forest further south in New South Wales. If cloud forest was to transform to a drier rainforest on Queensland parks, it may still persist within protected areas inter-State further south with the same level of protection. However, this kind of decision may provide a political backlash or high negative social implications. In many cases, this also is an important factor in decision making such as Australia where government operated national parks are answerable to the public.

In deciding the most appropriate management strategies for managing climate change impacts, parks should be managed individually, but within a regional context because of external influences and opportunities. For example, a particular species may be highly dependent on a particular park such as the stream dwelling frog *Philoria kundagungan* (restricted to Main Range in Queensland). Expensive, strategies such as hard engineering may become necessary to maintain stream dwelling frog habitat on Main Range because a decrease in population on this park may have a significant impact on the species survival.

From this research, it appears that some critical issues within the region are not currently managed well (i.e. threatened species, fire and feral animals, Table 3-5). Further investigation into these issues is required to understand probable barriers to additional management that may be required under climate change. Park managers require data analysis and good record keeping including monitoring and recording of how they are meeting their fire and pest strategies. There needs to be an assurance that well-developed fire strategies are being adhered to and that there are appropriate resources, including for wildfire disasters otherwise effective management cannot take place. For example, stream dwelling frog habitat will require strategic fire management objectives for wildfire mitigation (Chapter 4). Climate change predictions for the region (Chapter 1) indicate an increase in fire risk and the BBNs (Chapter 4) indicate fire management will be a significant factor in adapting park management for all three values. Strategies should be in place to reduce the risk of weeds that promote fire or change fire significantly and weeds that change the ability of systems to respond after disturbance (e.g. wildfires or severe storms).

A long term monitoring strategy specifically for climate change impacts and drivers of change should be developed for the parks across the region. Regular monitoring and having directions for alternative actions in place will increase the probability of success of strategies (Lawler et al. 2010). It should be understood that monitoring is not scientific research and should be kept simple and efficient (Abbott & Le Maitre 2010) otherwise it can become resource intensive and less likely to be adopted long term. Monitoring must be based on objectives and outcomes of implemented climate change adaptation strategies and not be undertaken for the sake of monitoring on an *ad hoc* basis (Abbott & Le Maitre 2010). Outcome focussed monitoring should measure the condition of those value, i.e. population trend of stream dwelling frogs, cool temperate forest health, and walking track condition (Chapter 4) with the purpose of obtaining desired outcomes set through the decision making process (Chapter 5). There must be purpose that ties into the management objectives of the park for effective park management (Hockings et al. 2006). Things to consider are monitoring of invasive species, particularly after disturbance such as wildfires and extreme weather events (expected to increase across South East Queensland), and species that drive change such as those that influence fire (Chapters 3 and 4).

Visitor monitoring is lacking for unknown reasons. Previous monitoring has included details on visitor numbers through track counters but has ceased to be collected (pers. comm. QPWS, walking track workshop participant, 2015), this should be increased, particularly as it appears many tracks are degrading across the region as a whole. The models (Chapter 4) show that an injection of resources and management are essential for adapting track management for climate change.

Scientific research is required on some more substantial aspects where there are data gaps. The BBNs outputs can focus research on more of the ecological features of the parks to assist adaptation to climate change. In Mount Barney for example, the models (Chapter 4) suggest this may be the most stable of the parks for stream dwelling frogs under climate change., However there is less (as compared to the other three Gondwana parks) relevant ecological data available for this park. Research and monitoring may confirm the model outputs and therefore the assessment of its viability for frog habitat under climate change.

#### ***6.7.1.1 Recommendations for three key values: stream dwelling frogs, cool temperate forest, walking tracks***

The two main concerns for stream dwelling frogs are increased impacts to the non-breeding and breeding habitat, and reduction in water. Increased awareness of and change in fire management to their dry non-breeding habitats will be required to adapt to changing climatic conditions. Increased feral pig management will be required in wet breeding habitats, particularly in drier periods when pigs are likely to be attracted to water sources. Investigation of hard and soft ecological engineering may need to be introduced if park management objectives include persistence of frogs.

Managing for change is recommended for the cool temperate forest with an emphasis on reducing impacts of climatic stressors such as weeds and introduced pathogens to encourage healthy forests during that transition. It will be important to manage fire in surrounding vegetation to reduce potential wildfires encroaching into the cool temperate forest, increasing rate of transition

Walking tracks will require increased resources. It is recommended to assess the entire track system across the region and prioritise tracks for maintenance and make decisions on which to maintain, to what standard, and which to 'let go' if resources are limited. Strategies such as re-routing tracks to less vulnerable areas and use of fire resistant materials will become more important under climate change.

## **6.8 Conclusion**

Adapting current protected area management for climate change is achievable. It will be challenging, and the process may be long, but it will be necessary if protected areas are to persist in a healthy and sustainable condition. Despite climate change predictions and ecological modelling slowly reducing the uncertainty around associated impacts and changes, the future state of protected areas is increasing in uncertainty because of the rate of climate change. Modifying park management will be a continual process and managers will have to maintain vigilance in dealing with climate change.

Park managers will have to become more adaptive and inventive in their approaches, particularly as new and surprising changes occur and impacts appear. They will have to become creative and 'think outside the box' to better deal with issues outside of their control. They will need to become a great deal more efficient in how they allocate and utilise their resources and make decisions that would, under a 'stationary' climate, have been seen as resulting in unacceptable loss.

We, as park managers and scientists have the knowledge to maintain productive and sustainable protected areas. We have the ability to continually learn and adapt, as humans have for thousands of years. Some parks may not appear like they have in the past, and that is something as a society we will have to accept to move forward in protected area management for the future.



# **Chapter 7**

## **Bibliography**



**Plate 7 – Fungi, Lanington National Park**

**‘When we show our respect for other living things,  
they respond with respect for us –  
Native American Proverb’**

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## Chapter 8

### Appendices



Plate 8 – Whitewater rockmaster *Diphlebia lestoides*, Springbrook National Park

**‘We are all visitors to this time, this place. We are just passing through. Our purpose here is to observe, to learn, to grow, to love, and then we return home.’ – Australian Aboriginal Proverb**

## 8.1 Appendix 1 – Scenic Rim Attributes

**Table 8-1 Climate change predictions for Springbrook, Lamington, Mount Barney and Main Range National parks 2090.**

|                                       | Springbrook | Lamington | Mount Barney | Main Range |
|---------------------------------------|-------------|-----------|--------------|------------|
| Current (Present average (1971–2000)) |             |           |              |            |
| Mean minimum temperature (°C)         | 12.6        | 12.6      | 9.5          | 9.5        |
| Mean maximum temperature (°C)         | 25.3        | 25.3      | 23.8         | 23.8       |
| Annual rainfall (mm)                  | 2052 mm     | 1807 mm   | 921 mm       | 1032 mm    |
| Severe storms (average no per year)   | 3.4         | 1.4       | 1.7          | 2.2        |
| 2090 average (low emissions)          |             |           |              |            |
| Mean minimum temperature (°C)         | 14.4        | 14.4      | 11.3         | 11.3       |
| Mean maximum temperature (°C)         | 27.2        | 27.2      | 25.7         | 25.7       |
| Annual rainfall (mm)                  | 1887.84     | 1662.44   | 847.32       | 949.44     |
| Severe storms (average no per year)   | 5.4         | 3.4       | 3.7          | 4.2        |
| 2090 average (high emissions)         |             |           |              |            |
| Mean minimum temperature (°C)         | 16.3        | 16.3      | 13.2         | 13.2       |
| Mean maximum temperature (°C)         | 28.9        | 28.9      | 27.4         | 27.4       |
| Annual rainfall (mm)                  | 1785.24     | 1572.09   | 801.27       | 897.84     |
| Severe storms (average no per year)   | 7.4         | 5.4       | 5.7          | 6.2        |

### Source for current averages

- Springbrook: Temperature - Tyalgum (Wanungara view), Station No 058057, Elevation 120m, distance from Springbrook National Park, approximately 17 kms; Rainfall – Springbrook Road, Station No 040607
- Lamington: Temperature - Tyalgum (Wanungara view), Station No 058057, Elevation 120m, distance from Lamington National Park, approximately 21 kms; Rainfall – Green Mountains, Station No 040182, Australian
- Mount Barney: Killarney Post Office, Station No 041056, Elevation 507 m, distance from Mt Barney National Park, approximately 40 kms; Rainfall – Mount Barney, Station No 040394
- Main Range National Park: Temperature –Killarney Post Office, Station No 041056, Elevation 507 m, distance from Main Range National Park, approximately 32 kms; Rainfall – Cunningham’s Gap, Station No 041456
- Australian Government, Bureau of Meteorology (<http://www.bom.gov.au/>) accessed 25/2/2014)

### Source for predictions

- Temperature and rainfall GCM simulated prediction periods relative to the 1986-2005 period for the East Coast Cluster, figures calculated on the annual median (50<sup>th</sup> percentile) change for RCP4.5 (low) and RCP8.5 (high) (Dowdy et al. 2015).
- Severe storms predictions (Whitfield et al. 2010)

**Table 8-2 Biodiversity values of four of the Scenic Rim's protected areas (Queensland Government 2011, 2013c, 2013b, 2013a; Queensland Herbarium 2014; Queensland Parks and Wildlife Service 2014).**

|  | Springbrook | Lamington | Mount Barney | Main Range |
|--|-------------|-----------|--------------|------------|
| Fauna (~ no. vertebrate species)       | 250         | 332       | 318          | 425        |
| Flora (~ no. vascular plants)          | 900         | 880       | 801          | 955        |
| Regional ecosystems (~ no. ecosystems) | 28          | 20        | 32           | 31         |
| Fungi (~ no. species)                  | 50          | 450       | 21           | 188        |
| Mosses (~ no. species)                 | 23          | 86        | 7            | 27         |

**Table 8-3 Attributes of the four Scenic Rim National Parks.**

|  | Springbrook | Lamington   | Mount Barney | Main Range |
|--|-------------|-------------|--------------|------------|
| Park size (ha)                                 | 6 555       | 20 590      | 17 660       | 30 274     |
| Boundary (kms)                                 | 235         | 200         | 267          | 419        |
| Altitude - highest peak (m)                    | 1000        | 1150        | 1359         | 1375       |
| * Adjacent land use (%)                        |             |             |              |            |
| Compatible                                     | 11          | 23          | 28           | 2          |
| Semi - compatible                              | 63          | 36          | 31           | 38         |
| Non - compatible                               | 26          | 51          | 41           | 60         |
| ** Current precipitation (mm)                  | 2052        | 1807        | 921          | 1032       |
| ** Current temperatures (C)                    | 12.6 – 25.3 | 12.6 – 25.3 | 9.5 – 23.8   | 9.5 – 23.8 |
| *** Current # severe storms                    | 3.4         | 1.4         | 1.7          | 2.2        |
| Walking tracks – graded class 1-4 (approx. km) | 27          | 140         | 14.2         | 65         |
| Cool temperate forest (approx. ha)             | 3           | 519         | 98           | 672        |

\* Landuse was categorised into compatible (National park, dam/reservoir, production forestry), semi-compatible (plantation forestry, residual native cover) and non-compatible (residential, livestock grazing cropping, intensive animal production).

\*\* Current precipitation and temperatures were taken from the closest weather station to the National Park from the Australian Bureau of Meteorology

\*\*\* Severe storms baseline data are based on the Australian Government's Bureau of Meteorology's Storm Archive. This is a record of severe thunderstorm and related events. Many storms are not recorded, for a number of reasons, therefore this is a guide only and not necessarily the exact number. The figure represents severe storms (severe rain events, hail, severe wind events and tornados) recorded on or in close vicinity to the protected area.

## 8.2 Appendix 2 - Survey

### General climate change questions

For the purposes of this survey, 'climate change' is considered to have the same meaning as 'global warming'.

1. Have you heard of climate change?

☐ yes

☐ no

☐ unsure

2. In a short sentence, please describe what you think climate change is.

3. What do you believe are the top three causes of climate change?

### Climate change impacts

4. Please rate the significance of the following causes of climate change.

|   | High<br>significance     |                          | Significant              |                          | Low<br>significance      | No<br>significance       | Don't<br>know            |
|---|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Agricultural practices                    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Carbon emissions from burning natural gas | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Carbon emissions from coal and oil        | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Forest destruction / land clearing        | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Landfill                                  | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Methane emissions                         | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Ozone layer damage                        | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Pollution                                 | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Other _____                               | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

5. Please rate the significance of the following impacts of climate change on a global scale.

|   | High<br>impact           |                          |                          | Medium<br>impact         |                          |                          | Low<br>impact            |                          | No impact                |                          | Don't<br>know            |
|---|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Increase in global average temperature            | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Longer/colder winters                             | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Increase in extreme weather events, e.g. cyclones | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Changes in sea temperature                        | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Decrease in snow                                  | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Ice cap melting                                   | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Change in water quality/quantity                  | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Increase in fire frequency and intensity          | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Changes in ocean salinity                         | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Changes in rainfall                               | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Increase in sea level                             | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Increase in floods                                | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Glacier melting                                   | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Increase in drought                               | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Impact on food production and security            | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

6. Please rate the significance of the following impacts of climate change on the natural environment in your local area.

|   | High impact              |                          |                          | Medium impact            |                          |                          | Low impact               |                          | NO impact                |                          | Don't know               |
|---|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Local extinction of native animals                                | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Local extinction of native plants                                 | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Change in vegetation types  | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Increase in weeds   | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Change in breeding times for animals                              | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Change in flowering times in plants                               | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Restriction of plant and animal movement throughout the landscape | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Increase in feral animals   | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

7. Please indicate how concerned you are about climate change in general.

|                  |                          |                          |                          |                          |                          |                          |                          |                          |
|------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
|                  | Very high<br>concern     |                          |                          | Moderate<br>concern      |                          |                          | Very low<br>concern      | Not<br>concerned         |
| Level of concern | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

8. Please look the following list of things that climate change may impact on and tick three (3) things that concern you most.

- |   |  |
|---|--|
| <input type="checkbox"/> Native plants                      | <input type="checkbox"/> Lifestyle                   |
| <input type="checkbox"/> Water supplies                     | <input type="checkbox"/> More extreme weather events |
| <input type="checkbox"/> Public health                      | <input type="checkbox"/> Native animals              |
| <input type="checkbox"/> Protected areas                    | <input type="checkbox"/> Agriculture                 |
| <input type="checkbox"/> The natural environment in general | <input type="checkbox"/> Australian economy          |
| <input type="checkbox"/> Coast communities                  |  |

### Protected areas

For the purposes of this survey, the term ‘protected area’ includes any national or state owned land set aside for protection of the natural environment including national parks, conservation parks, state forests, forest reserves, scientific areas and resource reserves.

9. What is your closest local protected area?

10. How close do you live to this protected area?

(kilometres) .....

11. Do you have any other protected areas nearby and how far are these from where you live?



The following questions relate to the protected area that you live closest to as indicated in question 9.

12. How often do you visit this protected area?

- ☐ Daily
- ☐ More than once a week
- ☐ Weekly
- ☐ Monthly
- ☐ Once or twice a year
- ☐ Other (please specify how many times a year) .....

13. Do you know why this protected area is important and why it is protected?

- ☐ No
- ☐ Yes, but only limited knowledge
- ☐ Yes, average knowledge
- ☐ Yes, very good knowledge
- ☐ Unsure

If yes, please give details of the significant values of this protected area.

14. Please rate the following issues that may currently threaten this protected area.

|  | Very high<br>threat      |                          |                          | Medium<br>threat         |                          | Very low<br>threat       | No threat                | Don't<br>know            |
|--|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Residential and commercial development                   | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Recreational activities                                  | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Fire and fire management                                 | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Weeds  | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Energy production and mining                             | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Hunting and collecting animals                           | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Transportation corridors (e.g. roads)                    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Inappropriate management                                 | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Large temperature changes                                | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Dams and water management/use                            | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Storms and flooding                                      | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Logging and wood harvesting                              | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Collecting plants  | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Introduced animals                                       | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Agriculture  | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Illegal human activities (e.g. vandalism,<br>trailbikes) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Geological events (e.g. landslides)                      | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Utility services (e.g. powerlines)                       | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Fishing  | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Drought  | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Pollution  | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Changes in habitat from climate change                   | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Fragmentation of native vegetation                       | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

15. What impression do you have of the following issues when you visit the park?

|   | Very good                |                          |                          | Average                  |                          | Very poor                | Don't know               |
|---|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| How well fire is managed                              | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| The amount of pollution                               | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| The amount of weeds                                   | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| How well the water is managed                         | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Commercial tourism                                    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| The amount of feral animals                           | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Management of threatened species                      | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Illegal human activities (e.g. vandalism, trailbikes) | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| The fragmentation of native vegetation                | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| The state of recreation facilities                    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

16. Based on your current knowledge and understanding of climate change, please indicate how much climate change in general will impact on this protected area?

|                               | High impact              |                          |                          | Medium impact            |                          |                          | Low impact               | NO impact                |
|-------------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| General climate change impact | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

17. Do you believe we need to change current management of this protected area to cope with climate change impacts?

- ☐ yes
- ☐ no
- ☐ unsure

If yes, is there anything you would change or introduce?

## General information

18. What is the postcode of where you live?

.....

19. What is your age?

.....

20. Please indicate your annual household income (before tax)?

- ☐ Less than \$30 000
- ☐ \$30 000 - \$60 000
- ☐ \$60 000 - \$90 000
- ☐ \$90 000 - \$120 000
- ☐ Greater than \$120 000

21. What is your highest level of education?

- ☐ School certificate (Yr 10)
- ☐ High school certificate (Yr 12)
- ☐ TAFE certificate/diploma/trade
- ☐ University degree

22. What is your job/profession?

.....

Thankyou for your participation

### 8.3 Appendix 3 - Additional survey and interview questions for Queensland Parks and Wildlife Staff

For the purposes of this survey, the term ‘protected area’ includes any national or state owned land set aside for protection of the natural environment including national parks, conservation parks, state forests, forest reserves, scientific areas and resource reserves

- Which protected areas on the list do you currently manage?
- What are the significant values of this/these protected area/s and why have they been set aside for protection?
- Do you think these significant values are under threat now or in the future?
- What monitoring, if any takes place on these protected areas?
- What management strategies are required given climate change? What objectives would this achieve?
- What are your views on interventionist proposals such as assisted migration?
- What do you foresee in the way of social challenges where implementation of adaptive strategies are concerned?
- What do you see as the barriers to trying new things and becoming ‘ecosystem engineers’?
- What kind of additional tools or management frameworks would you like to have to assist you in managing protected areas under future climate change?

Please indicate how concerned you consider DERM is about the following subjects.

|   | Very concerned           |                          |                          | Medium concern           |                          |                          | Not concerned            |
|---|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Protection of the natural environment in general    | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Climate change in general                           | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Impact of climate change on the natural environment | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Impact of climate change on protected areas         | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Impact of climate change on native animals          | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Impact of climate change on native plants           | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |
| Impact of climate change on water supplies          | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

## **8.4 Appendix 4 - Bayesian belief networks**

#### 8.4.1 Data table for the Bayesian belief network for stream dwelling frogs

| Variable         | Discretisation methodology   | Information source/type | Baseline (current)   | States   |
|------------------|--|-------------------------|--|--|
| Precipitation    | Based on average monthly rainfalls of closest station (Australian Bureau of Meteorology) | IPCC/BOM                | <b>SPRINGBROOK</b><br>2052 mm<br><b>LAMINGTON</b><br>1807 mm<br><b>MOUNT BARNEY</b><br>921 mm<br><b>MAIN RANGE</b><br>1032 mm  | <b>High decrease</b> (- 10%)<br><b>Low decrease</b> (- 7.5%)<br><b>Current</b>   |
| Temperature      | Based on average temperatures of closest station (Australian Bureau of Meteorology)      | IPCC/BOM                | <b>SPRINGBROOK</b><br>Average minimum 12.6°C, maximum 25.3°C<br><b>LAMINGTON</b><br>Average minimum 12.6°C, maximum 25.3°C<br><b>MOUNT BARNEY</b><br>Average minimum 9.5°C, maximum 23.8°C<br><b>MAIN RANGE</b><br>Average minimum 9.5°C, maximum 23.8°C | <b>High increase</b> (+3.4°C)<br><b>Low increase</b> (+1.8°C)<br><b>Current</b>  |
| Water management | Level of management to ensure appropriate amounts of water (i.e. water extraction)       | Literature/expert       | Sustainable use  | <b>Appropriate</b> (sustainable use – frog species and/or their habitat is not impacted upon )<br><b>Not appropriate</b> (not sustainable use) |
| * Severe storms  | Based on Australian Bureau of Meteorology recorded severe storms                         | IPCC/BOM                | <b>SPRINGBROOK</b><br>3.4 severe storms / year<br><b>LAMINGTON</b><br>1.4 severe storms / year<br><b>MOUNT BARNEY</b><br>1.7 severe storms / year<br><b>MAIN RANGE</b><br>2.2 severe storms / year   | <b>High increase</b> (+ 6% windspeed, +4 days hail risk/year)<br><b>Low increase</b> (+3% windspeed, +2 days hail risk/year)<br><b>Current</b> |

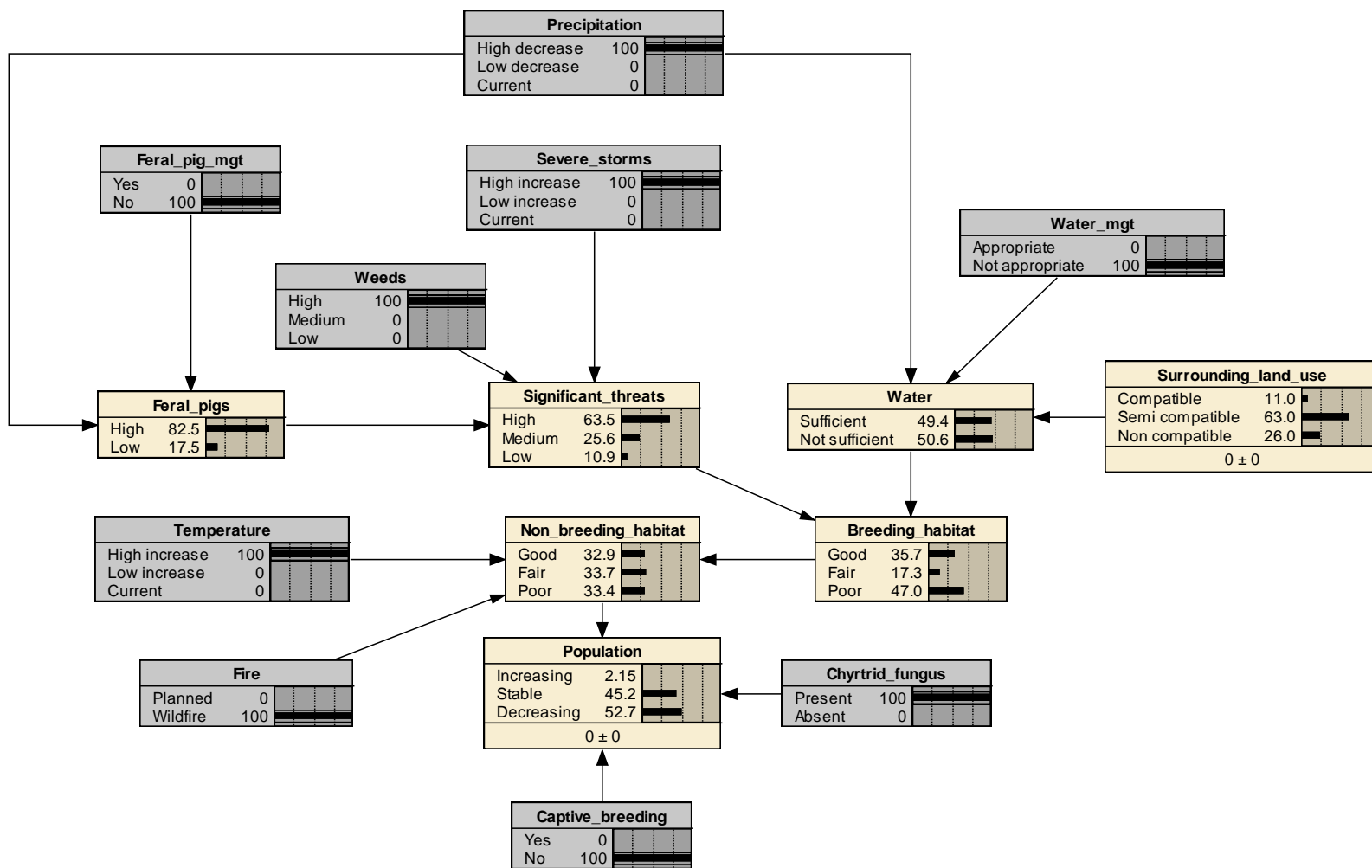
|                      |  |                        |   |   |
|----------------------|--|------------------------|---|---|
| Surrounding land use | Calculated from Queensland Government 'Queensland Land use Current' data using designated criteria       | GIS/Literature         | <b>SPRINGBROOK</b><br>11 % Compatible<br>63 % Semi-compatible<br>26 % Non-compatible<br><hr/> <b>LAMINGTON</b><br>23 % Compatible<br>26 % Semi-compatible<br>51 % Non-compatible<br><hr/> <b>MOUNT BARNEY</b><br>28 % Compatible<br>31 % Semi-compatible<br>41 % Non-compatible<br><hr/> <b>MAIN RANGE</b><br>2 % Compatible<br>38 % Semi-compatible<br>60 % Non-compatible | <b>Compatible</b> (National park, dam/reservoir, production forestry)<br><b>Semi-compatible</b> (Plantation forestry residual native cover)<br><b>Non-compatible</b> (Residential, livestock grazing cropping, intensive animal production,)  |
| Significant threats  | Deterministic variable of weeds, feral pigs and severe storms  | Literature/expert      |   | <b>High</b> (> 75% of value is threatened and threat is likely to lead to a loss of the value in the foreseeable future if it continues to operate at current levels)<br><b>Medium</b> (26-75% of value is threatened and threat will lead to significant reduction of value is it continues to operate at current levels)<br><b>Low</b> (< 25% of value is threatened and only minor or barely detectable impact on the value) |
| Weeds                | Level of weed threat   | Literature/expert      |   | <b>High</b> (> 75% of value is threatened and threat is likely to lead to a loss of the value in the foreseeable future if it continues to operate at current levels)<br><b>Medium</b> (26-75% of value is threatened and threat will lead to significant reduction of value is it continues to operate at current levels)<br><b>Low</b> (< 25% of value is threatened and only minor or barely detectable impact on the value) |
| Feral pigs           | Level of feral pig impacts. Categorical variable as a function of feral pig management and precipitation | Literature/expert/QPWS | Low   | <b>High</b> (> 50% of value is threatened and threat is likely to lead to a loss of the value in the foreseeable future if it continues to operate at current levels)<br><b>Low</b> (< 50% of value is threatened and only minor or barely detectable impact on the value)  |
| Feral pig management | Is there effective feral pig management in place   |                        | No  | <b>Yes</b> (Effective feral pig management is undertaken in all known frog wet habitat)<br><b>No</b> (Effective feral pig management is NOT being undertaken in any frog wet habitat)   |
| Captive breeding     | Is a captive breeding program occurring for 1 or more species of the frogs                               |                        | No  | <b>Yes</b><br><b>No</b>   |
| Fire                 | Appropriate and regular planned burning to reduce or eliminate wildfires                                 |                        | No wildfires  | <b>Planned</b> (Park planned burning program implemented (with none or 1 wildfire per 20 years) maintaining a healthy habitat)  |



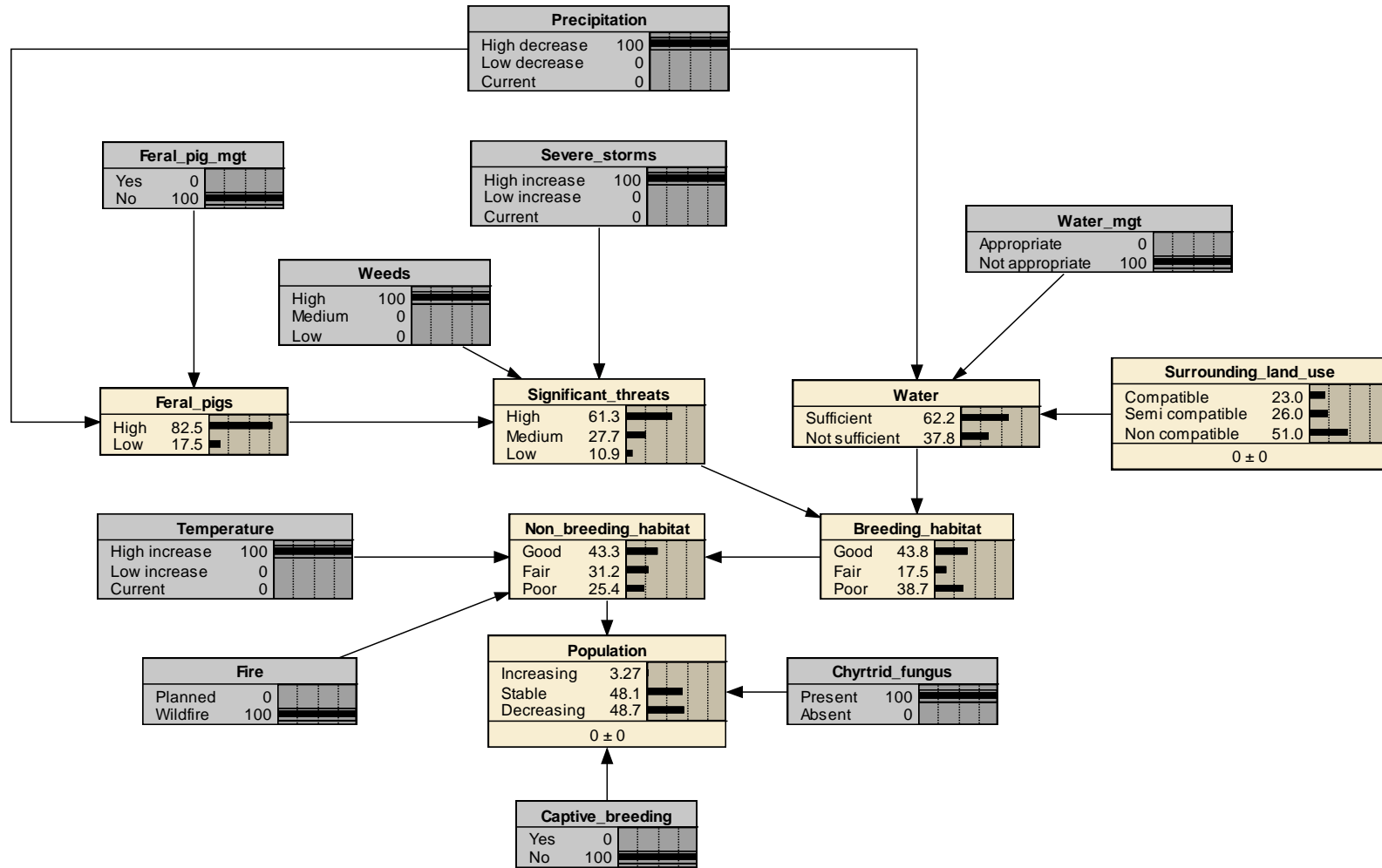
|                      |   |                   |   |   |
|----------------------|---|-------------------|---|---|
|                      |   |                   |   | <b>Wildfire</b> (Park planned burning program reduced resulting in 1 or more wildfires every 10 years. Insufficient planned burning or wildfires reduce health of habitat to POOR and or impacts upon adult population) |
| Water                | Categorical variable as a function of climate change, water management and surrounding land use for sufficient amount of water to support breeding habitat  | Literature/expert |   | <b>Sufficient</b> (sufficient water to support breeding habitat)<br><b>Not sufficient</b> (not sufficient water to support breeding habitat)  |
| Breeding habitat     | Wet habitat where eggs and tadpoles inhabit. Categorical variable as a function of significant threats and water to maintain a breeding habitat to enable a viable population of tadpoles for migration to a non-breeding habitat | Literature/expert |   | <b>Good</b> (QUALITY > 75% of habitat in very good condition)<br><b>Fair</b> (QUALITY 75 – 26% of habitat in very good condition)<br><b>Poor</b> (QUALITY < 25% of habitat in very good condition)                      |
| Non breeding habitat | Dry habitat and adult frogs. Categorical variable as a function of fire (quality of habitat), temperature (physiological impact upon adults) and breeding habitat quality (recruitment from water/stream habitat)                 | Literature/expert |   | <b>Good</b> (QUALITY > 75% of habitat in very good condition)<br><b>Fair</b> (QUALITY 75 – 26% of habitat in very good condition)<br><b>Poor</b> (QUALITY < 25% of habitat in very good condition)                      |
| Population           | Categorical variable as a function of captive breeding, non-breeding and chytrid fungus to ensure a stable or increasing population of stream dwelling frogs  | Literature/expert |   | <b>Increasing</b> (population increasing from present numbers)<br><b>Stable</b> (population stable at present numbers)<br><b>Decreasing</b> (population decreasing below present numbers)                               |
| Chytrid fungus       | Deterministic variable of climate change  | Literature/expert | Present but not causing declines at the moment. | <b>Present</b> (increasing infection of population above current occurrence)<br><b>Absent</b> (decreasing infection of population below current occurrence)   |

\* Severe storms baseline data are based on the Australian Government’s Bureau of Meteorology’s Storm Archive. This is a record of severe thunderstorm and related events. Many storms are not recorded, for a number of reasons, therefore this is a guide only and not necessarily the exact number. The figure represents severe storms (severe rain events, hail, severe wind events and tornados) recorded on or in close vicinity to the protected area.

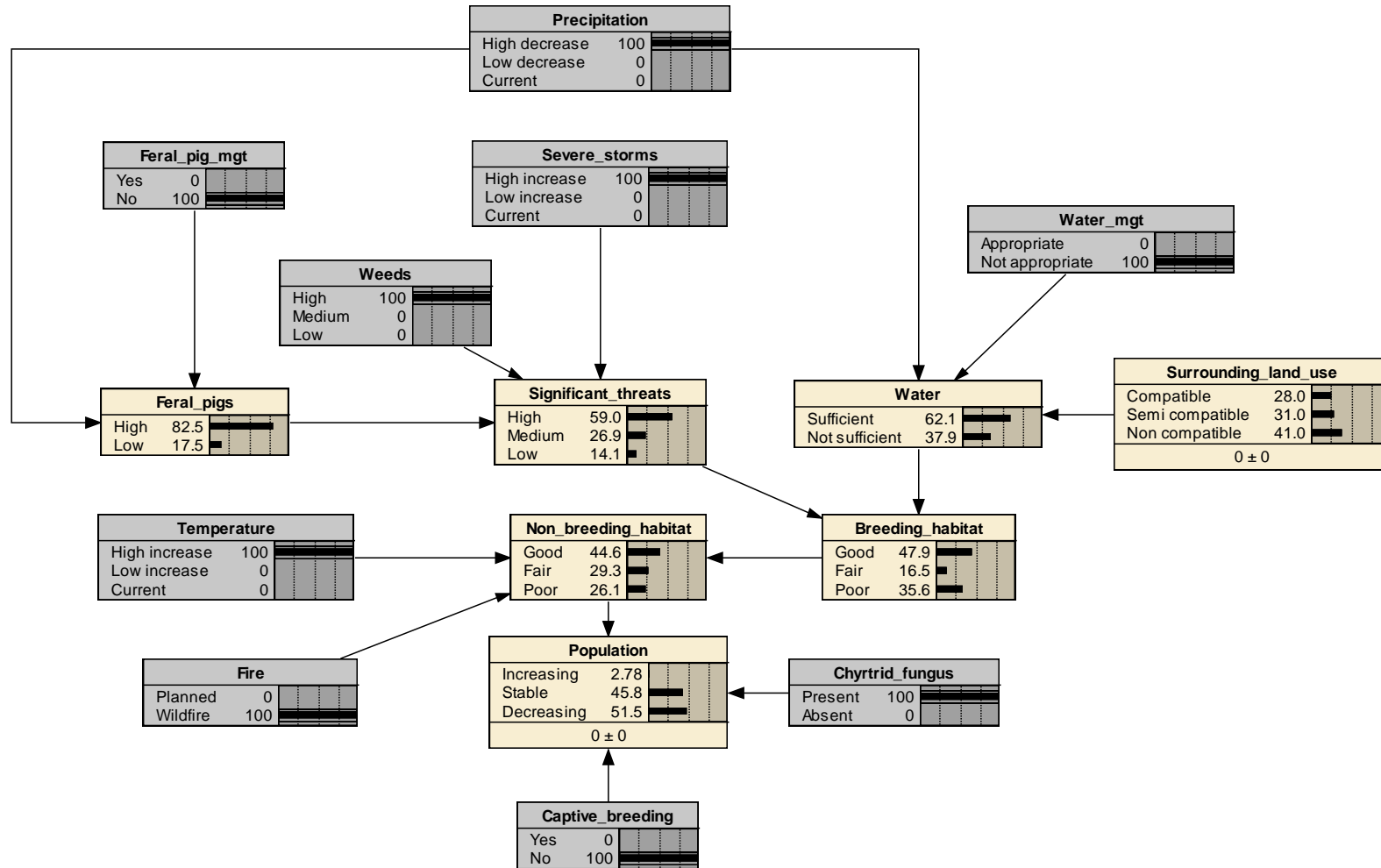
#### 8.4.2 Bayesian belief network, stream dwelling frogs, Springbrook National Park – ‘worst case’ scenario



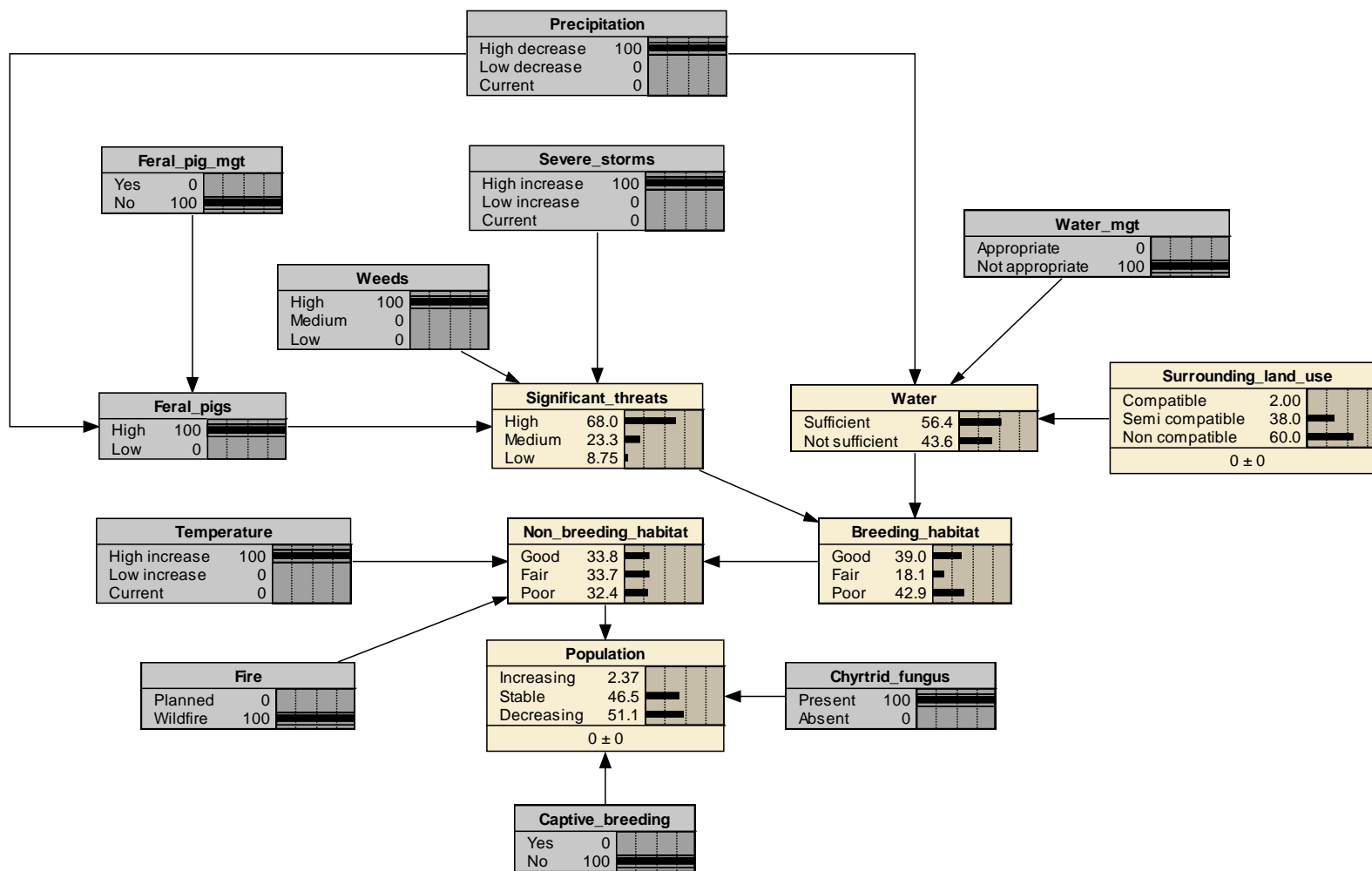
#### 8.4.3 Bayesian belief network, stream dwelling frogs, Lamington National Park – ‘worst case’ scenario



#### 8.4.4 Bayesian belief network, stream dwelling frogs, Mount Barney National Park – ‘worst case’ scenario



#### 8.4.5 Bayesian belief network, stream dwelling frogs, Main Range National Park – ‘worst case’ scenario



#### 8.4.6 Data table for the Bayesian belief network cool temperate forest

| Variable                    | Discretisation methodology  | Information source/type | Baseline   | States  |
|-----------------------------|---|-------------------------|--|---|
| Temperature                 | Based on average temperatures of closest station (Australian Bureau of Meteorology)                             | IPCC/BOM                | <b>SPRINGBROOK</b><br>Average minimum 12.6°C, maximum 25.3°C | <b>High increase</b> (+3.4°C)<br><b>Low increase</b> (+1.8°C)<br><b>Current</b>   |
|                             |   |                         | <b>LAMINGTON</b><br>Average minimum 12.6°C, maximum 25.3°C   |   |
|                             |   |                         | <b>MOUNT BARNEY</b><br>Average minimum 9.5°C, maximum 23.8°C |   |
|                             |   |                         | <b>MAIN RANGE</b><br>Average minimum 9.5°C, maximum 23.8°C   |   |
| Precipitation               | Based on average monthly rainfalls of closest station (Australian Bureau of Meteorology)                        | IPCC/BOM                | <b>SPRINGBROOK</b><br>2052 mm                                | <b>High decrease</b> (- 10%)<br><b>Low decrease</b> (- 7.5%)<br><b>Current</b>  |
|                             |   |                         | <b>LAMINGTON</b><br>1807 mm                                  |   |
|                             |   |                         | <b>MOUNT BARNEY</b><br>921 mm                                |   |
|                             |   |                         | <b>MAIN RANGE</b><br>1032 mm                                 |   |
| Fire management             | Planned burning of surrounding ecosystems to protect rainforest and maintain bordering eucalypt forests         | Literature/QPWS/Expert  |  | <b>Good</b> (> 70% of planned burning objectives met and/or no wildfires)<br><b>Poor</b> (< 70% of planned burning objectives met and/or wildfire presence that encroaches into Cool temperate rainforest)  |
| Fire                        | Appropriate and regular planned burning to reduce or eliminate wildfires  | Expert                  |  | <b>Planned</b> (Park planned burning program implemented with no wildfires present, planned burning maintains healthy forest)<br><b>Wildfire</b> (Park planned burning program reduced resulting in 1 or more wildfires per 20 years. Insufficient planned burning or wildfires reduce health of CTF ecosystems to GOOD or below) |
| Expansion of non CTF plants | The amount of encroachment of non-Cool Temperate Forest species as a categorical variable for fire and dry days | Expert                  | No encroachment  | <b>Current</b><br><b>Moderate increase</b> (+25% Encroachment into cool temperate forest)<br><b>High increase</b> (50% Encroachment into cool temperate forest)   |

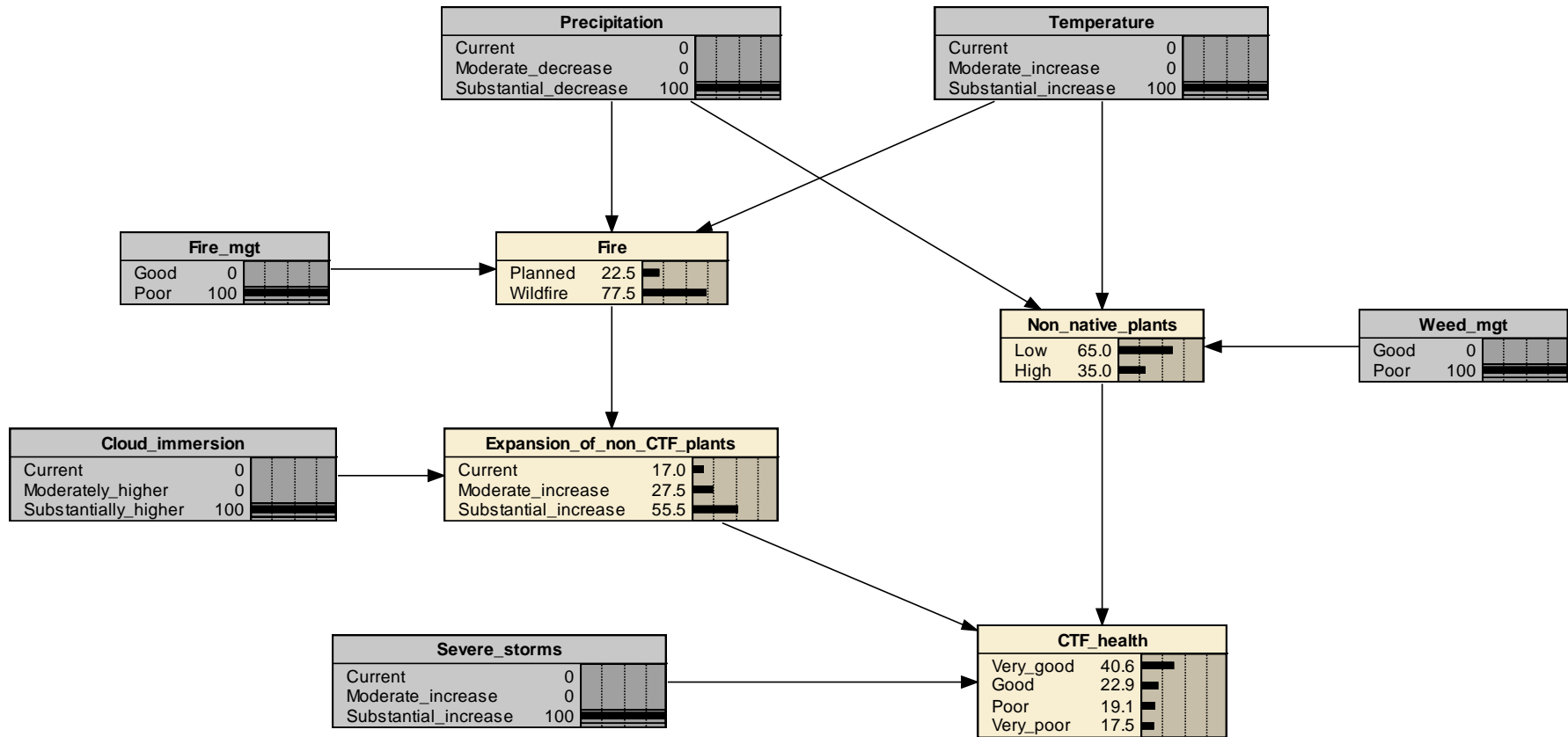
|                   |  |                   |   |  |
|-------------------|--|-------------------|---|--|
| * Severe storms   | Based on Australian Bureau of Meteorology recorded severe storms   | IPCC/BOM          | <b>SPRINGBROOK</b><br>3.4 severe storms / year  | <b>High increase</b> (+ 6% windspeed, +4 days hail risk/year)<br><b>Low increase</b> (+3% windspeed, +2 days hail risk/year)<br><b>Current</b>   |
|                   |  |                   | <b>LAMINGTON</b><br>1.4 severe storms / year    |  |
|                   |  |                   | <b>MOUNT BARNEY</b><br>1.7 severe storms / year |  |
|                   |  |                   | <b>MAIN RANGE</b><br>2.2 severe storms / year   |  |
| Non-native plants | Impact on Cool Temperate Forest that warrants sufficient management to maintain it in good to very good condition          | Literature/Expert |   | <b>High</b> (> 50% of value is threatened and threat is likely to lead to a loss of the value in the foreseeable future if it continues to operate at current levels)<br><b>Low</b> (< 50% of value is threatened and only minor or barely detectable impact on the value) |
| Weed management   |  | Expert            |   | <b>Good</b> –(management of weed species is appropriate – no detrimental impact, non-native plants are maintained as a LOW impact)<br><b>Poor</b> - (management of weed species is not appropriate, non-native plants are not maintained as a LOW impact)                  |
| Cloud immersion   | Increase in altitude of cloud cover as a categorical variable of temperature and precipitation (base of current cloud cap) | Literature/expert | 900 m   | <b>Substantially higher</b> (1100 m)<br><b>Moderately higher</b> (1000m)<br><b>Current</b>   |

|                              |   |        |   |
|------------------------------|---|--------|---|
| Cool temperate forest health | Categorical variable as a function of severe storms, expansion of non CTF plants, level of non native plants and impacts of light and evapotranspiration rates from increased light/sun | Expert | <p><b>Very good</b> – All current CTF ecosystems are essentially structurally and functionally intact and able to support all dependent species, no significant changes, only a few, if any species populations have deteriorated as a result of environmental conditions, few or no impacts have been observed</p> <p><b>Good</b> - There is some habitat loss, degradation or alteration in some small areas, leading to minimal degradation but no persistent substantial effects on populations of dependent species, there are some significant changes in processes in some areas, but are not to the extent that they are significantly affecting ecosystem function, populations of some species (but no species groups) have deteriorated significantly as a result of declining environmental conditions, some minor impacts have been observed</p> <p><b>Poor</b> - Habitat loss, degradation or alteration has occurred in a number of areas leading to persistent substantial effects on population of some dependent species, there are substantial changes in processes and are significantly affecting ecosystem functions in some areas, populations of many species or some species groups have deteriorated as a result of declining environmental conditions, current and predicted future impacts are likely to significantly affect the ecological values</p> <p><b>Very poor</b> - There is widespread habitat loss, degradation or alteration leading to persistent, substantial effects on many populations of dependent species, there are substantial changes in processes across a wide areas and ecosystem functions are seriously affected in much of the area, populations of large number of species have deteriorated significantly, current and predicted future impacts are likely to irreversibly destroy much of the CTF ecological values</p> |
|------------------------------|---|--------|---|

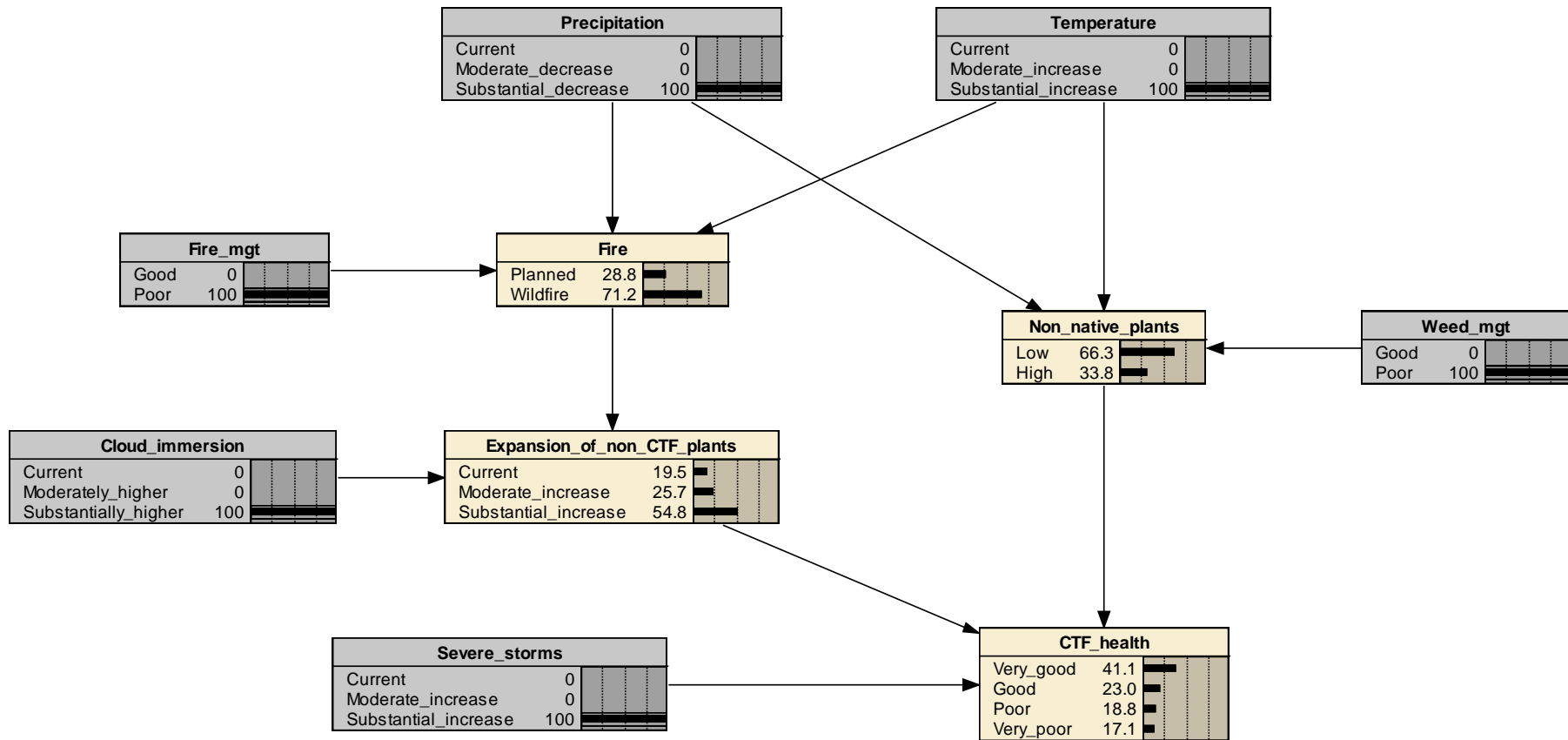
\* Severe storms baseline data are based on the Australian Government’s Bureau of Meteorology’s Storm Archive. This is a record of severe thunderstorm and related events. Many storms are not recorded, for a number of reasons, therefore this is a guide only and not necessarily the exact number. The figure represents severe storms (severe rain events, hail, severe wind events and tornados) recorded on or in close vicinity to the protected area.



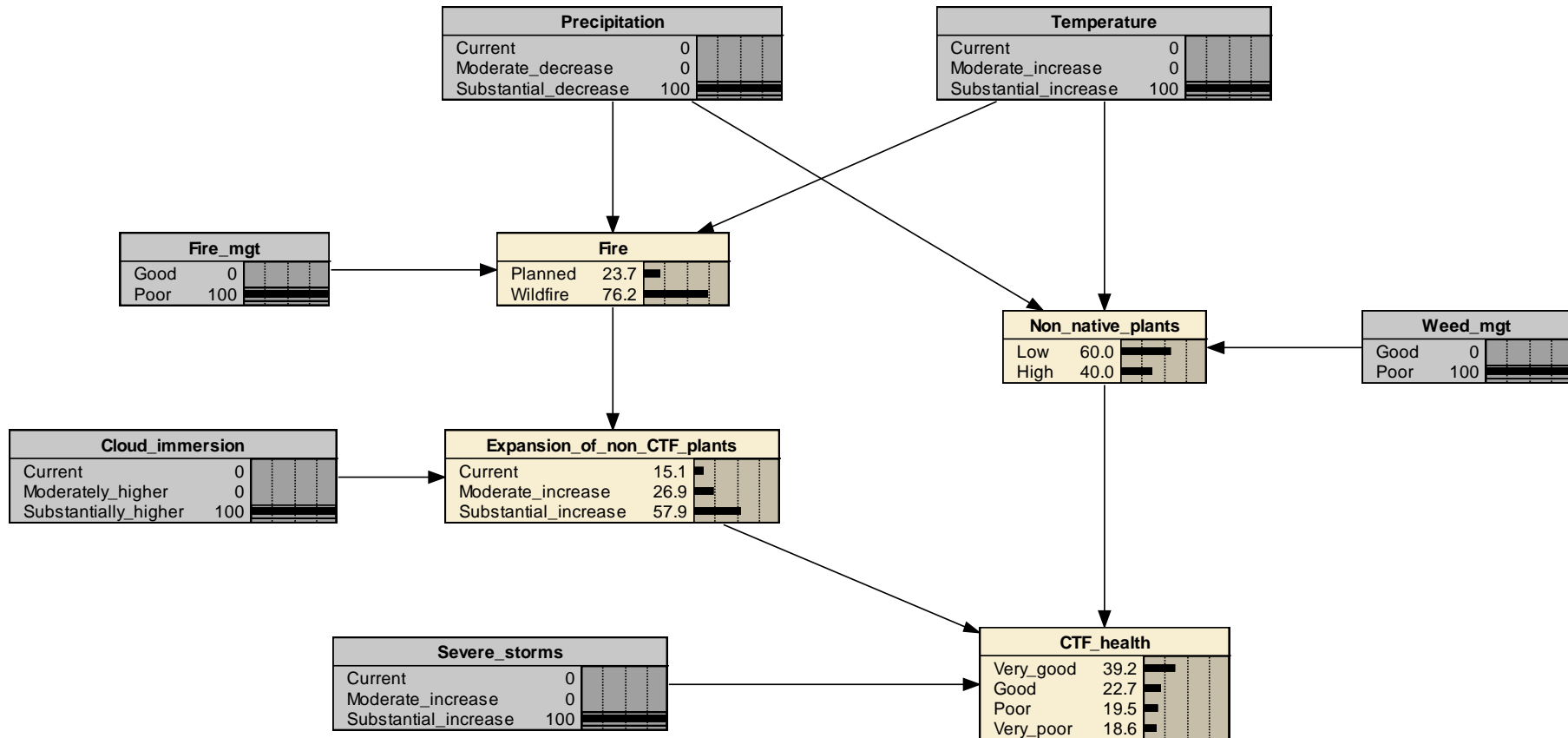
#### 8.4.7 Bayesian belief network, cool temperate forest, Springbrook National Park – ‘worst case’ scenario



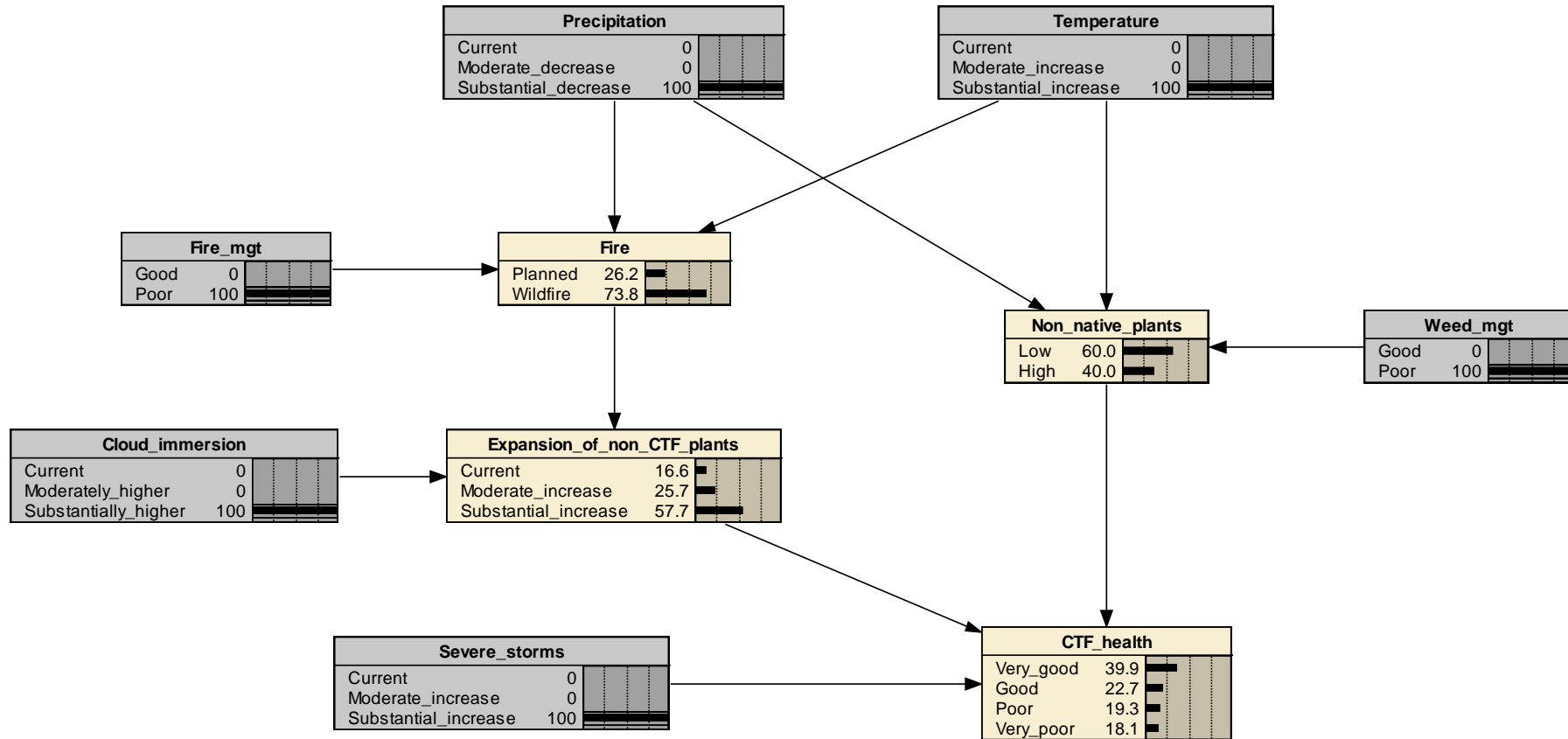
#### 8.4.8 Bayesian belief network, cool temperate forest, Lamington National Park – ‘worst case’ scenario



#### 8.4.9 Bayesian belief network, cool temperate forest, Mount Barney National Park – ‘worst case’ scenario



#### 8.4.10 Bayesian belief network, cool temperate forest, Main Range National Park – ‘worst case’ scenario



#### 8.4.11 Data table for the Bayesian belief network walking tracks

| Variable        | Discretisation methodology   | Information source/type       | Baseline   | States   |
|-----------------|--|-------------------------------|--|--|
| Temperature     | Based on average temperatures of closest station (Australian Bureau of Meteorology)      | IPCC/BOM                      | <b>SPRINGBROOK</b><br>Average minimum 12.6°C, maximum 25.3°C<br><b>LAMINGTON</b><br>Average minimum 12.6°C, maximum 25.3°C<br><b>MOUNT BARNEY</b><br>Average minimum 9.5°C, maximum 23.8°C<br><b>MAIN RANGE</b><br>Average minimum 9.5°C, maximum 23.8°C | <b>High increase</b> (+3.4°C)<br><b>Low increase</b> (+1.8°C)<br><b>Current</b>  |
| Precipitation   | Based on average monthly rainfalls of closest station (Australian Bureau of Meteorology) | IPCC/BOM                      | <b>SPRINGBROOK</b><br>2052 mm<br><b>LAMINGTON</b><br>1807 mm<br><b>MOUNT BARNEY</b><br>921 mm<br><b>MAIN RANGE</b><br>1032 mm  | <b>High decrease</b> (- 10%)<br><b>Low decrease</b> (- 7.5%)<br><b>Current</b>   |
| Fire management | Planned burning of surrounding area to protect tracks and associated infrastructure      |                               |  | <b>Appropriate</b> (>70 of planned burning objectives met)<br><b>Not appropriate</b> (<70% of planned burning objectives met)  |
| Resources       | Resources appropriate in maintaining walking tracks to a GOOD or above condition         | Park budget and work schedule |  | <b>Appropriate</b> (Appropriate number of staff and budget to maintain ALL tracks to standard)<br><b>Not appropriate</b> (Available staff and budget reduces the ability to maintain ALL tracks to standard)   |
| Wildfire        | Categorical variable as a function of fire management, precipitation and temperature     | Expert elicitation            |  | <b>Low</b> (No wildfires or < 1 per 20 years, with no impacts upon walking tracks and their associated infrastructure and their associated infrastructure visible)<br><b>High</b> (Park planned burning program reduced resulting in 1 or more wildfires every 10 years, with impacts upon walking tracks) |

|                              |   |                               |  |  |
|------------------------------|---|-------------------------------|--|--|
| Opportunities for management | Categorical variable as a function of resources and precipitation     | Expert elicitation            |  | <b>Yes</b> (Appropriate resources are allocated to park management budget, weather permits appropriate days of management for allocated staff)<br><b>No</b> (Appropriate resources are NOT allocated to park management budget, weather reduced appropriate number of days for management for allocated staff)   |
| Landslips                    | Categorical variable as a function of precipitation and severe storms | Literature/expert elicitation |  | <b>Low</b> (Equal to or below current landslips)<br><b>High</b> (Increase above current landslips)   |
| Tree falls                   | Categorical variable as a function of precipitation and severe storms | Literature/expert elicitation |  | <b>Low</b> (Equal to or below current tree falls)<br><b>High</b> (Increase above current treefalls)  |
| * Severe storms              | Based on Australian Bureau of Meteorology recorded severe storms      | IPCC/BOM                      | <b>SPRINGBROOK</b><br>3.4 severe storms / year<br><hr/> <b>LAMINGTON</b><br>1.4 severe storms / year<br><hr/> <b>MOUNT BARNEY</b><br>1.7 severe storms / year<br><hr/> <b>MAIN RANGE</b><br>2.2 severe storms / year | <b>High increase</b> (+ 6% windspeed, +4 days hail risk/year)<br><b>Low increase</b> (+3% windspeed, +2 days hail risk/year)<br><b>Current</b>   |
| Terrain                      | Terrain appropriate for walking tracks                                | Literature                    |  | <b>Suitable</b> <ul style="list-style-type: none"> <li>• Terrain slope &lt;10 (deg)</li> <li>• Soil (less coarse-textured soils)</li> <li>• Drainage – Normal, not boggy</li> <li>• Vegetation type (mature ecological communities, i.e. forest)</li> </ul> <b>Not suitable</b> <ul style="list-style-type: none"> <li>• Terrain slope &gt;10 (deg)</li> <li>• Soil (coarse-textured soils, i.e. based on gravel and sand)</li> <li>• Drainage – Boggy</li> <li>• Vegetation type (less mature ecological communities, i.e. grasses and heathlands)</li> </ul>   |
| Impact                       | Categorical variable as a function of landslips and tree falls        | Expert elicitation            |  | <b>Low</b> (Impacts from landslips, tree falls and visitation have current or minimal impact, threat is only minor or barely detectable upon walking tracks)<br><b>Medium</b> (Impacts from landslips, tree falls and/or visitation have an increased above current effects, threat will lead to a significant reduction of condition and some loss of availability of walking tracks)<br><b>High</b> (Impacts from landslips, tree falls and/or visitation is significantly above current effects, threat is likely to lead a loss of walking track condition and availability in the foreseeable future) |

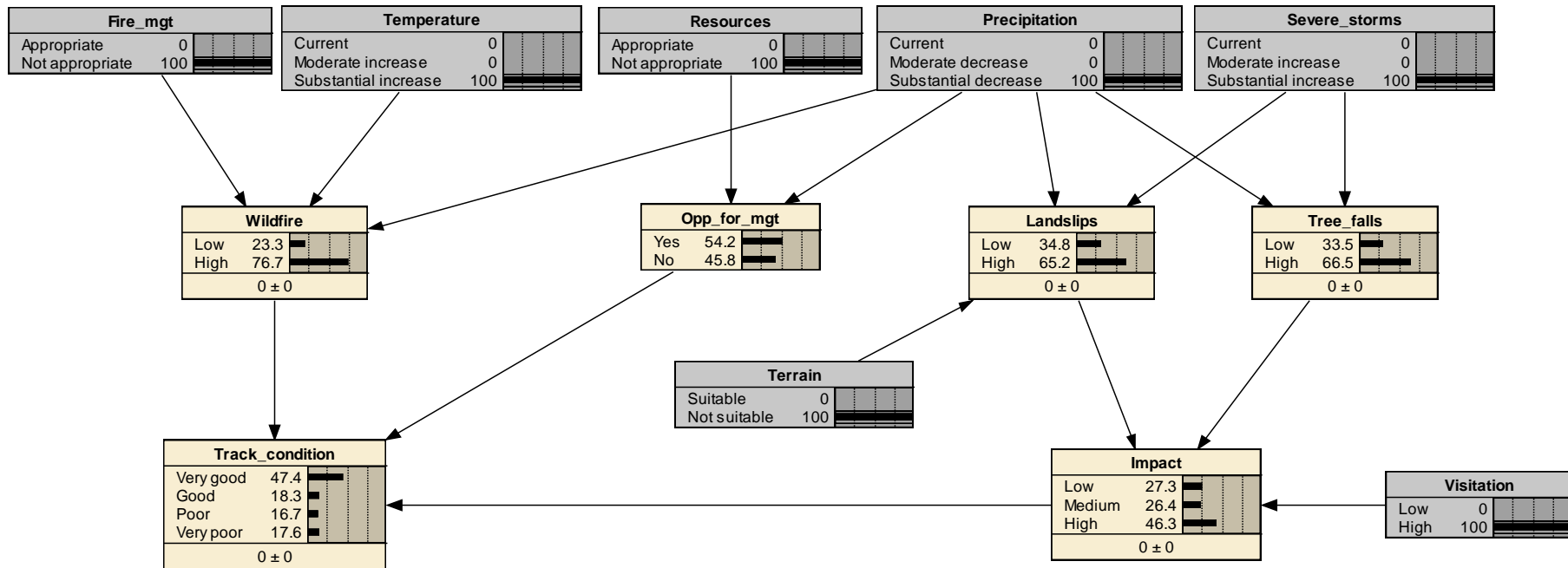
|                 |   |                    |   |
|-----------------|---|--------------------|---|
| Visitation      | Visitation appropriate for track classification   | Literature         | <b>Low</b> (passes per year is equal to or below the Australian Standard Guidelines)<br><b>High</b> (passes per year is above the Australian Standard Guidelines) |
| Track condition | Categorical variable as a function of wildlife requirements, wildfire and track maintenance | Expert elicitation | <b>Very good, good, poor, very poor</b> (see Track condition table below)   |

\* Severe storms baseline data are based on the Australian Government's Bureau of Meteorology's Storm Archive. This is a record of severe thunderstorm and related events. Many storms are not recorded, for a number of reasons, therefore this is a guide only and not necessarily the exact number. The figure represents severe storms (severe rain events, hail, severe wind events and tornados) recorded on or in close vicinity to the protected area.

### Track condition

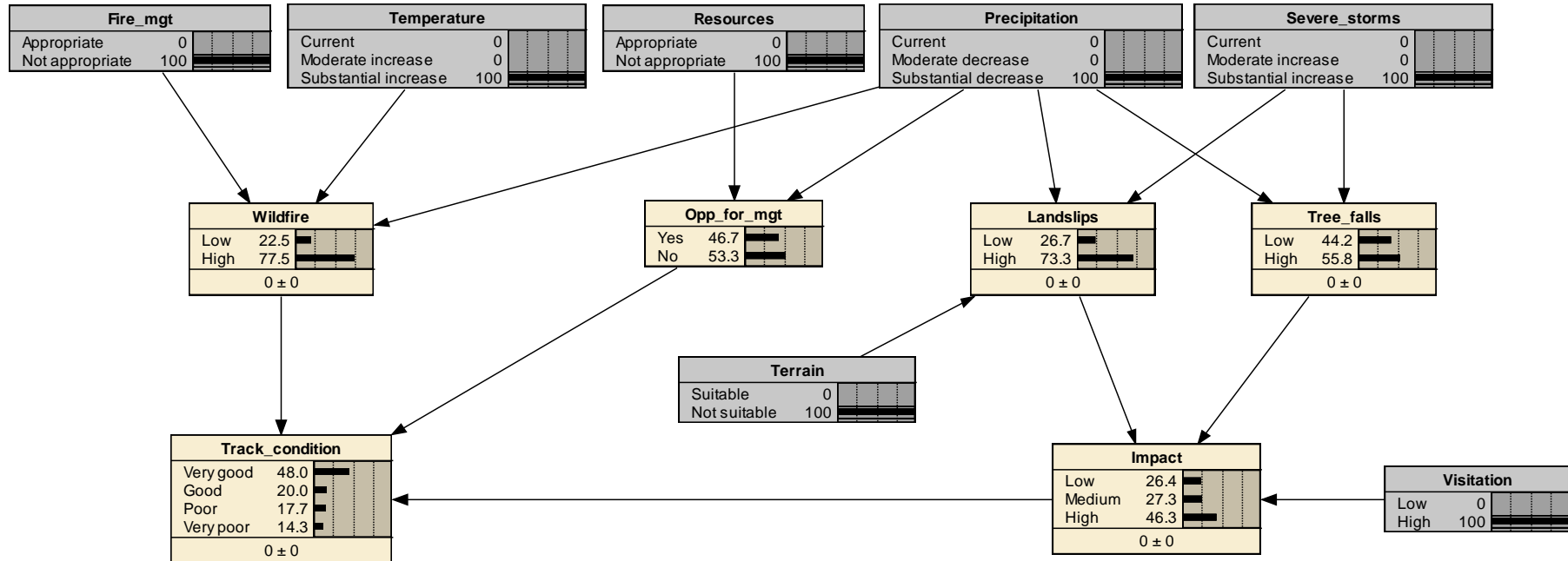
|                                   |        | % that meets the Australian walking track standard |           |           |           |
|-----------------------------------|--------|--|-----------|-----------|-----------|
|                                   |        | >75%   | 50-75%    | 25-50%    | <25%      |
| % of track open for public access | >75%   | VERY GOOD  | VERY GOOD | GOOD      | POOR      |
|                                   | 50-75% | GOOD   | GOOD      | POOR      | VERY POOR |
|                                   | 25-50% | POOR   | POOR      | VERY POOR | VERY POOR |
|                                   | <25%   | POOR   | VERY POOR | VERY POOR | VERY POOR |

#### 8.4.12 Bayesian belief network, walking tracks, Springbrook National Park – ‘worst case’ scenario

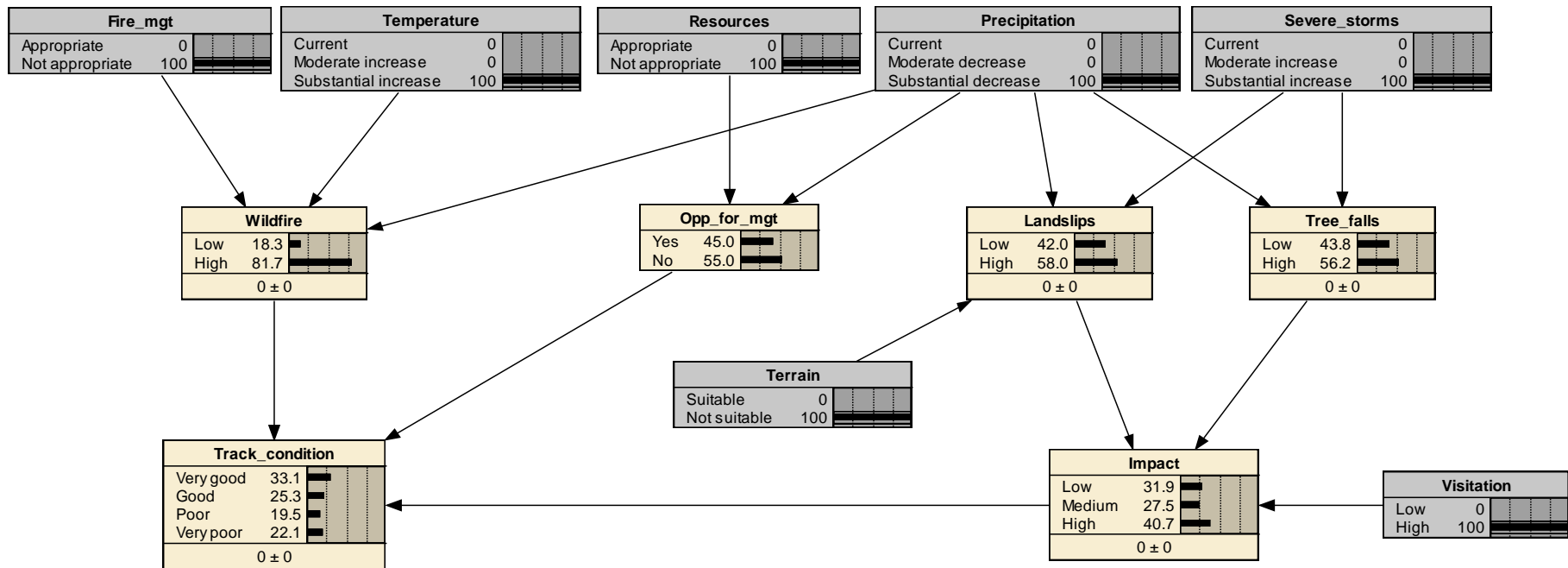




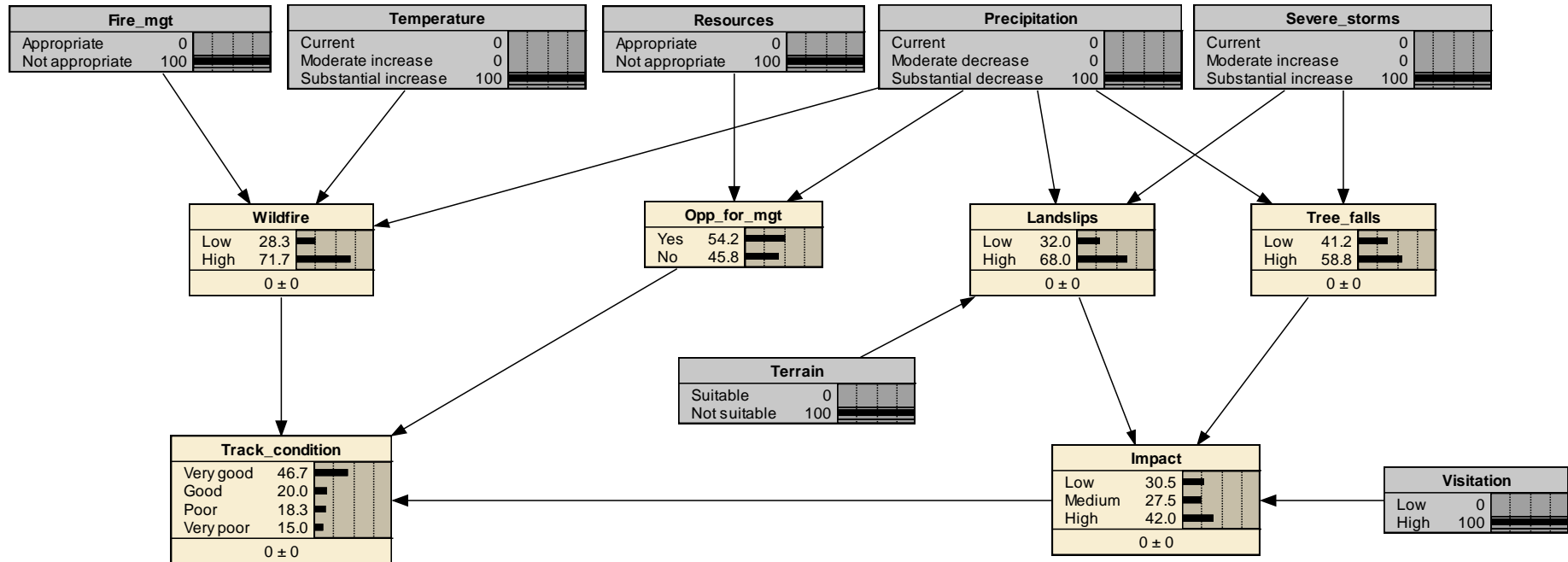
#### 8.4.13 Bayesian belief network, walking tracks, Lamington National Park – ‘worst case’ scenario



#### 8.4.14 Bayesian belief network, walking tracks, Mount Barney National Park – ‘worst case’ scenario



#### 8.4.15 Bayesian belief network, walking tracks, Main Range National Park – ‘worst case’ scenario



#### 8.4.16 Sensitivity analysis -

Table 8-4 Variance of beliefs under a ‘best case’ scenario.

|                              | Lamington        | Springbrook      | Mount Barney     | Main Range       |
|------------------------------|------------------|------------------|------------------|------------------|
| <b>Stream-dwelling frogs</b> |                  |                  |                  |                  |
| Non-breeding habitat         | 0.0004014        | <b>0.0005987</b> | 0.0001038        | 0.0004347        |
| Breeding habitat             | 0.0000426        | <b>0.0000769</b> | 0.0000047        | 0.0000407        |
| Water                        | 0.0000181        | <b>0.0000411</b> | 0.0000018        | 0.0000184        |
| Significant threats          | 0.0000021        | 0.0000017        | 0.0000002        | <b>0.0000022</b> |
| Surrounding land use         | 0.0000002        | <b>0.0000026</b> | 0.0000000        | 0.0000001        |
| Feral pigs                   | <b>0.0000001</b> | <b>0.0000001</b> | 0.0000000        | <b>0.0000001</b> |
| <b>Cool-temperate forest</b> |                  |                  |                  |                  |
| Expansion of non CTF         | 0.0035455        | 0.0036248        | <b>0.0036804</b> | 0.0036321        |
| Non-native plants            | 0.0002841        | 0.0002833        | 0.0003065        | <b>0.0003070</b> |
| Fire                         | 0.0000001        | 0.0000004        | <b>0.0000153</b> | 0.0000085        |
| <b>Walking track</b>         |                  |                  |                  |                  |
| Opportunity for management   | 0.0218388        | 0.0180823        | 0.0080762        | <b>0.0218553</b> |
| Impact                       | <b>0.0027669</b> | 0.0023739        | 0.0007623        | 0.0017750        |
| Landslips                    | <b>0.0004269</b> | 0.0001676        | 0.0000638        | 0.0001360        |
| Wildfire                     | 0.0000587        | <b>0.0009183</b> | 0.0004689        | 0.0007375        |
| Tree falls                   | <b>0.0000428</b> | 0.0000405        | 0.0000059        | 0.0000126        |

## **8.5 Appendix 5 - Participant information for decision making workshop**

### 8.5.1 Stream dwelling frogs

- For all parks, the population node was most sensitive to the non-breeding habitat, followed by breeding habitat then water
- All parks showed a lower probability of an increasing population and higher probability of a decreasing population under higher climate change scenarios with good management
- Presence of chytrid will have an impact on the probability of populations increasing above current numbers, it is a high uncertainty however good management has a positive affect

| Value importance for Springbrook NP  | Vulnerability of frogs for Springbrook NP   |
|--|---|
| <ul style="list-style-type: none"> <li>• <i>Mixophyes fleayi</i> (endangered EPBC and NCA), found in over 10 protected areas in Qld and NSW, scattered small populations</li> <li>• <i>Philoria loveridgei</i> (endangered IUCN), endangered in NSW, Extent of Occurrence is less than 5,000 km<sup>2</sup>, its distribution is severely fragmented, appears to be restricted to a few upland populations</li> <li>• <i>Litoria pearsoniana</i> (near threatened IUCN, vulnerable NCA), numerous good populations</li> <li>• <i>Mixophyes iterates</i> (endangered IUCN, NCA, and EPBC), no populations currently known</li> <li>• <i>Adelotus brevis</i> (near threatened IUCN, vulnerable NCA,), scattered populations/records, probably not abundant anywhere</li> </ul> | <ul style="list-style-type: none"> <li>• Highest sensitivity to non-breeding habitat in best and worst case scenarios</li> <li>• High sensitivity to wet, breeding habitat and water</li> <li>• Higher probability of a decreasing population under high climate change with wildfire</li> <li>• Sensitive to surrounding land use</li> </ul> |

| Value importance for Lamington NP  | Vulnerability of frogs for Lamington NP  |
|--|--|
| <ul style="list-style-type: none"> <li>• <i>Mixophyes fleayi</i> (endangered EPBC and NCA), found in over 10 protected areas in Qld and NSW, several good populations</li> <li>• <i>Philoria loveridgei</i> (endangered IUCN), endangered in NSW, Extent of Occurrence is less than 5,000 km<sup>2</sup>, its distribution is severely fragmented, numerous good populations over a range of altitudes, but mostly higher up</li> <li>• <i>Litoria pearsoniana</i> (near threatened IUCN, vulnerable NCA), numerous good populations</li> <li>• <i>Mixophyes iterates</i> (endangered IUCN, NCA, and EPBC), small populations in the lower reaches of Coomera and Canungra Creek (small compared to populations north of Brisbane)</li> <li>• <i>Adelotus brevis</i> (near threatened IUCN, vulnerable NCA,), scattered populations/records, probably not abundant anywhere</li> </ul> | <ul style="list-style-type: none"> <li>• Highest sensitivity to breeding habitat, water, and significant threats under a worst case scenario</li> <li>• Water extraction may be an issue under climate change for habitat</li> </ul> |

| Value importance for Mount Barney NP  | Vulnerability of frogs for Mount Barney NP   |
|---|--|
| <ul style="list-style-type: none"> <li>• <i>Mixophyes fleayi</i> (endangered EPBC and NCA), found in over 10 protected areas in Qld and NSW, only known from a few scattered very small populations but most suitable habitat not or poorly surveyed</li> <li>• <i>Philoria loveridgei</i> (endangered IUCN), endangered in NSW, Extent of Occurrence is less than 5,000 km<sup>2</sup>, its distribution is severely fragmented, known from a few scattered very small populations but most suitable habitat not or poorly surveyed, when surveyed the Mt Ballow – Nothofagus area resulted in fairly good numbers</li> <li>• <i>Litoria pearsoniana</i> (near threatened IUCN, vulnerable NCA), good populations but much poorly or unsurveyed habitat</li> <li>• <i>Mixophyes iterates</i> (endangered IUCN, NCA, and EPBC), no populations currently known</li> <li>• <i>Adelotus brevis</i> (near threatened IUCN, vulnerable NCA.), only a few records, survey effort poor</li> </ul> | <ul style="list-style-type: none"> <li>• The least sensitive park under a best and worst case scenario</li> <li>• Higher probability of a decreasing population under high climate change with wildfire</li> </ul> |



| Value importance for Main Range NP  | Vulnerability of frogs for Main Range NP  |
|---|---|
| <ul style="list-style-type: none"> <li>• <i>Mixophyes fleayi</i> (endangered EPBC and NCA), found in over 10 protected areas in Qld and NSW, several good populations</li> <li>• <i>Litoria pearsoniana</i> (near threatened IUCN, vulnerable NCA), numerous good populations</li> <li>• <i>Mixophyes iterates</i> (endangered IUCN, NCA, and EPBC), no populations currently known</li> <li>• <i>Adelotus brevis</i> (near threatened IUCN, vulnerable NCA), no populations currently known, there are a couple of recent records from areas adjacent to Main Range, so species likely to occur in the park but at very low densities, very patchy</li> <li>• <i>Phyloria kundagungan</i> (endangered IUCN, vulnerable NCA), in Queensland, restricted to Main Range, found in a couple of protected areas in NSW</li> </ul> | <ul style="list-style-type: none"> <li>• Higher probability of a decreasing population under high climate change with wildfire</li> </ul> |

### 8.5.2 Cool Temperate Forest (CTF)

- Climate change had a substantial effect on CTF on all four parks.
- Main threat is a loss of orographic cloud cover and moisture. This will result in a change in ecosystem structure to a non-CTF, for example drier rainforests such as coachwood dominated forests.
- A substantial increase in severe storms show a considerable decrease in the probability of maintaining very good CTF health.
- Current park management made relatively little difference to improving the condition of the CTF under climate change.
- CTF in Queensland is at its most northern extent, there are substantial representatives of this ecosystem in more southern protected areas in NSW.

| <b>Value importance for Springbrook NP</b>   | <b>Vulnerability of CTF for Springbrook NP</b>  |
|--|---|
| <ul style="list-style-type: none"><li>• One of the Outstanding Universal Values (OUV's) of the World Heritage criteria</li><li>• 3 ha of CTF which is approx. 0.23% of the total CTF in Queensland's Gondwana WH parks</li></ul> | <ul style="list-style-type: none"><li>• One of the least sensitive parks to weeds and showed a slight improvement with weed management</li><li>• Intermediate sensitivity to expansion of non-cool temperate forest ecosystems and fire</li></ul> |

| <b>Value importance for Lamington NP</b>  | <b>Vulnerability of CTF for Lamington NP</b>   |
|---|--|
| <ul style="list-style-type: none"><li>• One of the Outstanding Universal Values (OUV's) of the World Heritage criteria</li><li>• 519 ha of CTF which is approx. 40.17% of the total CTF in Queensland's Gondwana WH parks</li></ul> | <ul style="list-style-type: none"><li>• Very highly sensitive to expansion of non-cool temperate forest ecosystems</li><li>• One of the least sensitive parks to weeds</li><li>• The least sensitive park to fire</li><li>• Showed a slight improvement in cool temperate forest health with weed management</li></ul> |

| <b>Value importance for Mount Barney NP</b>  | <b>Vulnerability of CTF for Mount Barney NP</b>  |
|--|--|
| <ul style="list-style-type: none"> <li>• One of the Outstanding Universal Values (OUV's) of the World Heritage criteria</li> <li>• 98 ha of CTF which is approx. 7.59% of the total CTF in Queensland's Gondwana WH parks</li> </ul> | <ul style="list-style-type: none"> <li>• The least sensitive park to expansion of non-CTF ecosystems</li> <li>• Highly sensitive to weeds and fire</li> <li>• Showed some improvement in cool temperate forest health with weed and fire management</li> </ul> |

| <b>Value importance for Main Range NP</b>   | <b>Vulnerability of CTF for Main Range NP</b>  |
|---|--|
| <ul style="list-style-type: none"> <li>• One of the Outstanding Universal Values (OUV's) of the World Heritage criteria</li> <li>• 672 ha of CTF which is approx. 52% of the total CTF in Queensland's Gondwana WH parks</li> <li>• Slightly different CTF, dominated by <i>Acmena smithii</i></li> </ul> | <ul style="list-style-type: none"> <li>• Moderate sensitivity to expansion of non-cool temperate forest ecosystems, fire and weeds</li> <li>• Showed slight improvement in cool temperate forest health with weed and fire management</li> </ul> |

### 8.5.3 Walking tracks

- All park's track condition showed a very high sensitivity to opportunity for management, followed by impact, wildfire, landslips then treefalls
- All parks showed subtle changes to the probability of track condition under climate change depending on the type of terrain, management and visitation

| <b>Value importance for Springbrook NP</b>  | <b>Vulnerability of walking track condition for Springbrook NP</b>   |
|---|--|
| <ul style="list-style-type: none"><li>• Approximately 27 km of class 1 - 4 graded tracks</li><li>• Location close to the Gold Coast makes Springbrook a highly valued park for recreation and tourism, therefore the walking track system is important</li><li>• Part of the Great Walk</li></ul> | <ul style="list-style-type: none"><li>• Under a best case scenario, showed the highest sensitivity to wildfire</li><li>• Under a worst case scenario, showed the highest sensitivity to impact and wildfire</li><li>• Did not show a great deal of improvement in the probability of maintaining very good track condition under climate change with good or poor management</li></ul> |

| <b>Value importance for Lamington NP</b>  | <b>Vulnerability of walking track condition for Lamington NP</b>  |
|---|---|
| <ul style="list-style-type: none"><li>• Approximately 140 km of class 1 – 4 graded walking tracks</li><li>• Walking tracks system also have historical value</li><li>• Well known for bushwalking, including the many kilometres of class 5 – 6 wilderness tracks and overnight bush camping</li><li>• Park of the Great Walk</li></ul> | <ul style="list-style-type: none"><li>• Under a best case scenario, showed the highest sensitivity to opportunity for management, impact, landslips and tree falls</li><li>• Under a worst case scenario, showed the highest sensitivity to landslips (by an extensive amount), and tree falls</li><li>• Under a worst case scenario, showed the least sensitivity to wildfire (by an extensive amount)</li><li>• Showed an improvement in the probability of maintaining very good track condition under climate change with good management</li></ul> |

| <b>Value importance for Mount Barney NP</b>   | <b>Vulnerability of walking track condition for Mount Barney NP</b>   |
|---|---|
| <ul style="list-style-type: none"> <li>• Only approximately 14 km of graded 1 - 4 walking tracks</li> <li>• Opportunities for class 5 – 6 wilderness bushwalking</li> </ul> | <ul style="list-style-type: none"> <li>• Under a best and worst case scenario, showed the least sensitivity to opportunity for management, impact, landslips, and tree falls</li> <li>• Did not show a great deal of improvement in maintaining the probability of very good track condition under climate change with good management, however showed a decrease in the probability of very good track condition with poor management</li> </ul> |

| <b>Value importance for Main Range NP</b>  | <b>Vulnerability of walking track condition for Main Range NP</b>  |
|--|--|
| <ul style="list-style-type: none"> <li>• Approximately 65 km of class 1 – 4 graded walking tracks</li> <li>• Opportunities for class 5 – 6 wilderness bushwalking</li> </ul> | <ul style="list-style-type: none"> <li>• Under a best case scenario, showed the highest sensitivity to opportunity for management</li> <li>• Under a worst case scenario, showed the highest sensitivity to opportunity for management</li> <li>• Showed no substantial changes in the probability of maintaining very good track condition under climate change with good or poor management</li> </ul> |

#### 8.5.4 Implications, consequences and benefits (Stream dwelling frogs – Springbrook NP)

| Accept change  |  |  | Prevent change                       |   |  |
|--|--|--|--------------------------------------|---|--|
| Do nothing (accept damage or loss)   | Change management (build resilience)             | Modify existing system (change to new climate/environment)         | Hard engineering                     | Soft or ecological engineering                        | Change management/use (build resistance)     |
| Triage procedures, e.g. choosing to allow one or more species to decrease or be lost | Threat management (feral pigs), chytrid research | Modelling and managing future habitat for natural species movement | Water sprayers, irrigation, shelters | Revegetation, species translocation, captive breeding | Fire management to maintain breeding habitat |
| 0 1 2 3 4 5<br>None ----- V high   | 0 1 2 3 4 5<br>None ----- V high                 | 0 1 2 3 4 5<br>None ----- V high                                   | 0 1 2 3 4 5<br>None ----- V high     | 0 1 2 3 4 5<br>None ----- V high                      | 0 1 2 3 4 5<br>None ----- V high             |
| Cost   | 0 1 2 3 4 5<br>None ----- V high                 | 0 1 2 3 4 5<br>None ----- V high                                   | 0 1 2 3 4 5<br>None ----- V high     | 0 1 2 3 4 5<br>None ----- V high                      | 0 1 2 3 4 5<br>None ----- V high             |
| Social   | -3 -2 -1 0 1 2 3                                 | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3                     | -3 -2 -1 0 1 2 3                                      | -3 -2 -1 0 1 2 3                             |
| Ecological   | -3 -2 -1 0 1 2 3                                 | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3                     | -3 -2 -1 0 1 2 3                                      | -3 -2 -1 0 1 2 3                             |
| Economic   | -3 -2 -1 0 1 2 3                                 | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3                     | -3 -2 -1 0 1 2 3                                      | -3 -2 -1 0 1 2 3                             |
| Cultural   | -3 -2 -1 0 1 2 3                                 | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3                     | -3 -2 -1 0 1 2 3                                      | -3 -2 -1 0 1 2 3                             |
| Agency/political   | -3 -2 -1 0 1 2 3                                 | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3                     | -3 -2 -1 0 1 2 3                                      | -3 -2 -1 0 1 2 3                             |

### 8.5.5 Implications, consequences and benefits (Cool Temperate Forest – Springbrook NP)

|                        |  | Accept change                                    |  |  | Prevent change                   |   |  |
|------------------------|--|--|--|--|----------------------------------|---|--|
|                        |  | Do nothing (accept damage or loss)               | Change management (build resilience)                                   | Modify existing system (change to new climate/environment)         | Hard engineering                 | Soft or ecological engineering                          | Change management/use (build resistance)   |
|                        |  | Triage procedures – accept potential loss of CTF | Threat management, e.g. weeds and fire, but allow for ecosystem change | Modelling and managing future habitat for natural species movement | Man-made mist, irrigation, shade | Revegetation, seed banks and/or relocation of ecosystem | Manipulate or reduce fire management to halt drier forest types and encourage rainforest |
| Probability of success |  | 0 1 2 3 4 5<br>None ----- V high                 | 0 1 2 3 4 5<br>None ----- V high                                       | 0 1 2 3 4 5<br>None ----- V high                                   | 0 1 2 3 4 5<br>None ----- V high | 0 1 2 3 4 5<br>None ----- V high                        | 0 1 2 3 4 5<br>None ----- V high   |
| Cost                   |  | 0 1 2 3 4 5<br>None ----- V high                 | 0 1 2 3 4 5<br>None ----- V high                                       | 0 1 2 3 4 5<br>None ----- V high                                   | 0 1 2 3 4 5<br>None ----- V high | 0 1 2 3 4 5<br>None ----- V high                        | 0 1 2 3 4 5<br>None ----- V high   |
| Social                 |  | -3 -2 -1 0 1 2 3                                 | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3                 | -3 -2 -1 0 1 2 3  | -3 -2 -1 0 1 2 3   |
| Ecological             |  | -3 -2 -1 0 1 2 3                                 | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3                 | -3 -2 -1 0 1 2 3  | -3 -2 -1 0 1 2 3   |
| Economic               |  | -3 -2 -1 0 1 2 3                                 | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3                 | -3 -2 -1 0 1 2 3  | -3 -2 -1 0 1 2 3   |
| Cultural               |  | -3 -2 -1 0 1 2 3                                 | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3                 | -3 -2 -1 0 1 2 3  | -3 -2 -1 0 1 2 3   |
| Agency/political       |  | -3 -2 -1 0 1 2 3                                 | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3                 | -3 -2 -1 0 1 2 3  | -3 -2 -1 0 1 2 3   |

### 8.5.6 Implications, consequences and benefits (Walking tracks – Springbrook NP)

|                        |  | Accept change   |  |  | Prevent change  |  |  |
|------------------------|--|---|--|--|---|--|--|
|                        |  | Do nothing (accept damage or loss)                                | Change management (build resilience)   | Modify existing system (change to new climate/environment) | Hard engineering  | Soft or ecological engineering   | Change management/use (build resistance)   |
|                        |  | Walking tracks will slowly degrade below standard, loss of tracks | Reduce management to maintain tracks at a lower standard, or change track condition requirements | Re-route walking tracks or remove/reduce impacted tracks   | Maintaining and improving tracks with hard engineering, i.e. harder track surfaces, concrete/steel structures | Low impact changes to the environment to reduce impacts, soft engineering that blend in with the environment | Change management to combat impacts, e.g. increase staff or reroute resources, engage external contractors |
| Probability of success |  | 0 1 2 3 4 5<br>None ----- V high                                  | 0 1 2 3 4 5<br>None ----- V high   | 0 1 2 3 4 5<br>None ----- V high                           | 0 1 2 3 4 5<br>None ----- V high  | 0 1 2 3 4 5<br>None ----- V high   | 0 1 2 3 4 5<br>None ----- V high   |
| Cost                   |  | 0 1 2 3 4 5<br>None ----- V high                                  | 0 1 2 3 4 5<br>None ----- V high   | 0 1 2 3 4 5<br>None ----- V high                           | 0 1 2 3 4 5<br>None ----- V high  | 0 1 2 3 4 5<br>None ----- V high   | 0 1 2 3 4 5<br>None ----- V high   |
| Social                 |  | -3 -2 -1 0 1 2 3  | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3  | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3   |
| Ecological             |  | -3 -2 -1 0 1 2 3  | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3  | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3   |
| Economic               |  | -3 -2 -1 0 1 2 3  | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3  | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3   |
| Cultural               |  | -3 -2 -1 0 1 2 3  | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3  | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3   |
| Agency/political       |  | -3 -2 -1 0 1 2 3  | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3  | -3 -2 -1 0 1 2 3   | -3 -2 -1 0 1 2 3   |



